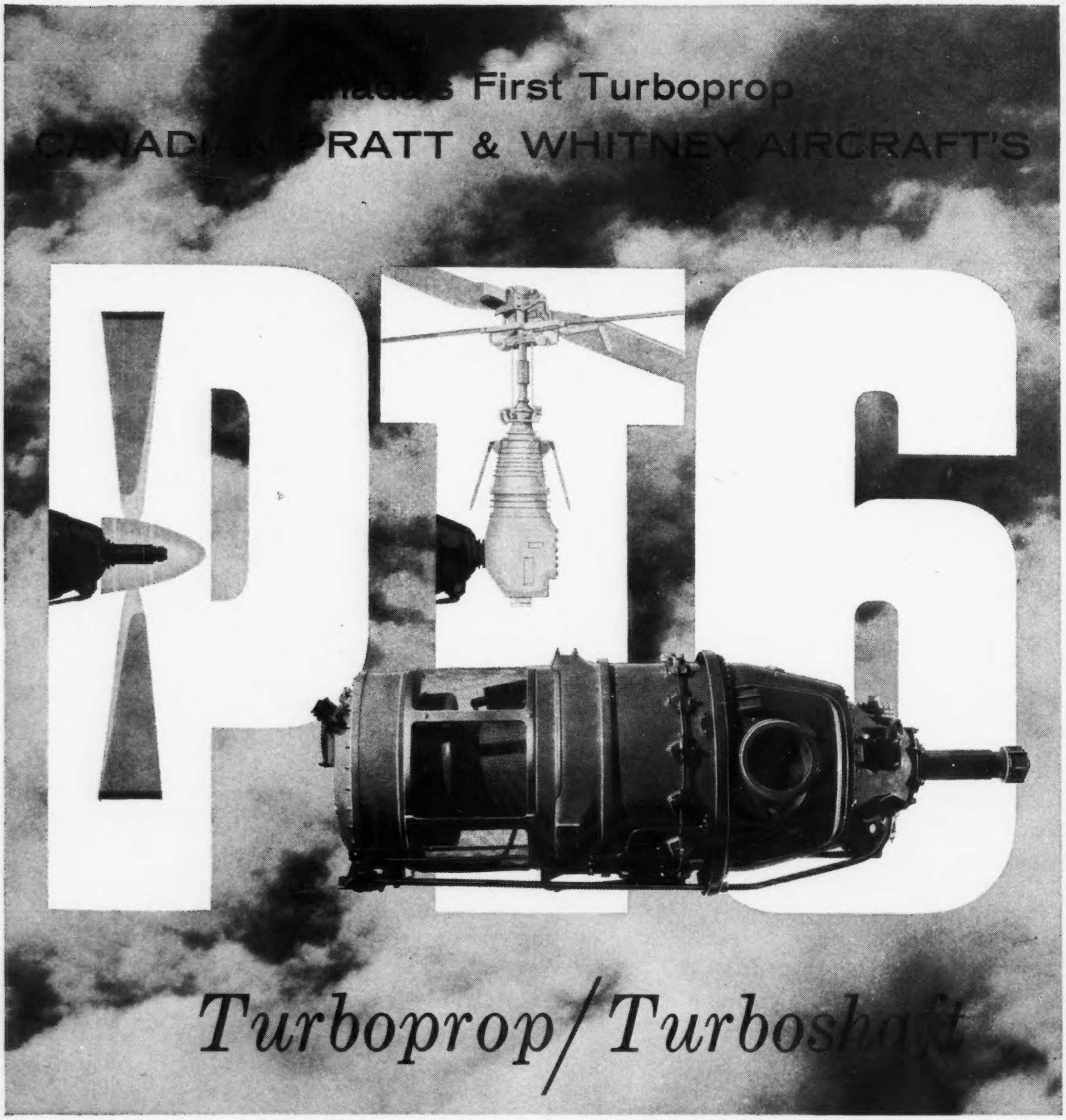
Volume 6 December 1960 No. 10

CANADIAN AERONAUTICAL INSTITUTE

Canadian Aeronautical Journal

CONTENTS

Published by the
CANADIAN AERONAUTICAL INSTITUTE
Commonwealth Building, 77 Metcalfe Street
OTTAWA



A remarkably versatile engine, the lightweight 500 horsepower PT6 has been designed to meet many needs . . . single and multi-engine fixed wing aircraft . . . helicopters and high speed marine installations. It offers a new concept in engine design . . . an axial-centrifugal flow, moderate pressure ratio turbine engine with a free turbine drive for either turboprop or turboshaft installations. This rugged 225-pound engine offers dependable performance, combined with low fuel consumption and ease of maintenance. It is Canada's first turboprop engine.

Available in 1961 from: *Canadian Pratt & Whitney Aircraft*

COMPANY, LIMITED, Longueuil, Montreal, P.Q.

Applications from experienced and qualified engineers are invited.

PRATT & WHITNEY ENGINES • SIKORSKY HELICOPTERS • HAMILTON STANDARD PRODUCTS • NORDEN ELECTRONICS • PESCO AIRCRAFT ACCESSORIES

VERTICAL FLIGHT CONTROL BY PRESSURE ALTITUDE: A REVISED SYSTEM OF ALTIMETRY — **S/L W. R. Fryers**

An altitude-indicating system for aircraft using pressure units only is presented. The pressure altitude indicator is proposed as a replacement for the conventional altimeter. The millibar is the proposed scale unit. Techniques for use are discussed.

CANADIAN AERONAUTICAL JOURNAL
Vol. 6, No. 10: Page 426, December 1960

FUTURE USES OF SPACE VEHICLES

This paper describes the uses to which spac
decade and covers both military and civil app

CANAD
Vol.

OF AIRCRAFT — **K. J. Orlik-Rukemann**
TIVES

determination of dynamic stability derivatives
g to a convenient classification system. Both
s are considered.

CANADIAN AERONAUTICAL JOURNAL
Vol. 6, No. 10: Page 414, December 1960

VEHICLES **K. J. Radford**

to which space vehicles may be put in the next
y and civil applications.

CANADIAN AERONAUTICAL JOURNAL
Vol. 6, No. 10: Page 423, December 1960

RELIABILITY-MAINTAINABILITY ENGINEERING OF AIRCRAFT, WEAPON AND ELECTRONIC SUPPORT SYSTEMS **C. I. Soucy**

An assessment of the progress in reliability-maintainability engineering and an evaluation of the state-of-the-art and current levels: some speculation on future needs and on what can be done to assure or hasten their attainment.

CANADIAN AERONAUTICAL JOURNAL
Vol. 6, No. 10: Page 400, December 1960

**METHODS OF MEASUREMENT OF AIRCRA
DYNAMIC STABILITY DERIVATIVES**

The numerous methods available for determination
are presented and grouped according to a conve
free flight and wind tunnel methods are considere

CANADIAN
Vol. 6, N

A MAN HAS FLOWN BY HIS OWN POWER IN 1937 **Enea Bossi**

An account of the author's experiments with man-powered flight.

CANADIAN AERONAUTICAL JOURNAL
Vol. 6, No. 10: Page 395, December 1960

A MAN HAS FLOWN BY HIS OWN POWER IN 1937 — **Enea Bossi**

An account of the author's experiments with man-powered flight.

CANADIAN AERONAUTICAL JOURNAL
Vol. 6, No. 10: Page 395, December 1960

METHODS OF MEASUREMENT OF AIRC
DYNAMIC STABILITY DERIVATIVES

The numerous methods available for determinat
are presented and grouped according to a con
free flight and wind tunnel methods are consid

CANADI
Vol. 6

RELIABILITY-MAINTAINABILITY ENGINEERING OF AIRCRAFT, WEAPON AND ELECTRONIC SUPPORT SYSTEMS — **C. I. Soucy**

An assessment of the progress in reliability-maintainability engineering and an evaluation of the state-of-the-art and current levels: some speculation on future needs and on what can be done to assure or hasten their attainment.

CANADIAN AERONAUTICAL JOURNAL
Vol. 6, No. 10: Page 400, December 1960

HICLES — **K. J. Radford**

which space vehicles may be put in the next
nd civil applications.

CANADIAN AERONAUTICAL JOURNAL
Vol. 6, No. 10: Page 423, December 1960

VERTICAL FLIGHT CONTROL BY PRESSURE ALTITUDE: A REVISED SYSTEM OF ALTIMETRY

S/L W. R. Fryers

An altitude-indicating system for aircraft using pressure units only is presented. The pressure altitude indicator is proposed as a replacement for the conventional altimeter. The millibar is the proposed scale unit. Techniques for use are discussed.

CANADIAN AERONAUTICAL JOURNAL

Vol. 6, No. 10: Page 426, December 1960

FUTURE USES OF SPACE VEHICLES

This paper describes the uses to which space
decade and covers both military and civil applic

CANADIAN

Vol. 6,

NT OF AIRCRAFT
VATIVES

K. J. Orlick-Rukemann

for determination of dynamic stability derivatives
ding to a convenient classification system. Both
ods are considered.

CANADIAN AERONAUTICAL JOURNAL

Vol. 6, No. 10: Page 414, December 1960

...low-cost but high performance!

BL-1705 Mounting System — shown protecting pressure transducer.

vibration control for aircraft instruments

Here's a new Lord mounting system for small equipment or instruments on jet aircraft that offers big advantages!

It's versatile. Basic design is adaptable to a variety of units: transducers, indicators, electronic tubes, gages, warning and timing devices, baroswitches. Mounting arrangements permit use in instrument panel, nacelle or other airframe locations.

It's high-performance. Lightweight system provides excellent all-attitude control of high-frequency excitations plus attenuation of shock and structure-borne noise. BTR® Elastomeric Mountings possess extreme environmental resistance, excellent damping, superior endurance, consistent performance over −65° to +300°F. range.

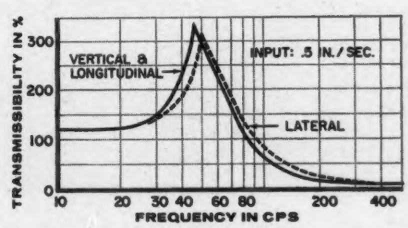
It's economical. Simplified design gives you Lord quality at a lower price than competitive bases. Long service life means your maintenance costs will be lower, too.

It's proved. The advanced design and performance of this Lord system have been thoroughly proved in actual service on today's jet airliners.

This mounting system is an example of Lord ingenuity. It indicates why you can continue to expect Lord to produce the best in vibration/shock/noise control for the aerospace environment. To put this ingenuity to work on your project, or to get further data on the BL-1705 base, contact *the nearest office of Railway & Power Engineering Corporation, Limited.*

typical specifications

Application: pressure transducer. **Weight:** equipment — 1.2 lbs., base — .38 lbs. **Shock/vibration protection:** all-attitude. **Isolators:** four Special BTR Multiplane Mountings. **System natural frequency:** 45 cps. **Operating temperature range:** −65° to +300°F. **Environmental resistance:** unaffected by fungi, dust, sand, salt atmosphere, oil, ozone. **Construction:** center-of-gravity suspension, fail-safe. **Mounting arrangements:** clearance holes or clinch nuts for base, bulkhead or overhead attachment.



LORD®

RAILWAY & POWER
Engineering Corporation, Limited

NEW GLASGOW · QUEBEC · MONTREAL · NORANDA · NORTH BAY · OTTAWA · TORONTO · HAMILTON · WINDSOR · SAULT STE. MARIE · WINNIPEG · CALGARY · EDMONTON · VANCOUVER

CANADIAN AERONAUTICAL INSTITUTE

CANADIAN AERONAUTICAL JOURNAL

Publications Committee

Mr. J. J. Eden, *Chairman*
G/C A. A. Buchanan
Mr. D. H. E. Cross
Mr. H. C. Oatway

Editor

Mr. W. A. Chisholm

Subscription—$4.00 a year. Single copy—50 cents

Bound Volumes—Orders for binding readers' own copies will be accepted in January and February, 1961, at $5.00 a volume.

Published monthly, except July and August

The Institute is not responsible for statements or opinions expressed in papers or discussions printed in its publications.

All communications should be addressed to The Secretary, Canadian Aeronautical Institute, 77 Metcalfe St, Ottawa 4, Ontario, Canada

Authorized as second class mail, Post Office Department, Ottawa

Printed by The Runge Press Ltd., Ottawa, Ontario, Canada

HMCS BONAVENTURE

The largest unit in the Royal Canadian Navy: the light fleet carrier HMCS Bonaventure, with a displacement of 20,000 tons and a complement of over 1,000 officers and men.

EDITORIAL

NAVAL AIR

THE Royal Canadian Navy, now celebrating its 50th Anniversary, is deeply involved in aviation.

The Navy's prime role today lies in being prepared to combat the submarine. Submarines have always been elusive targets and they show signs of becoming even more so. In World War II, aircraft flown from both carriers and shore bases played a vital role in denying the submarine his objective. The advance of technology has by no means lessened the importance of aircraft in this role; quite the reverse, anti-submarine aircraft today comprise a major sinew of the defending forces.

The Navy's anti-submarine aircraft in 1960 are the CS2F-2 Tracker and the HO4S Helicopter. The CS2F-2 Tracker, based on a Grumman design, is built by De Havilland at Downsview, Ontario. This aircraft has had great demands placed upon it. It must carry complex and delicate instruments of detection and attack and, in addition, it must be capable of flying from the deck of a carrier in all but the very worst conditions of sea and visibility. The Tracker has measured up to these stringent requirements and provides the Navy with a potent weapon.

The helicopter is coming increasingly to the fore as a means of dealing with the submarine. By virtue of its unique qualities of speed, manoeuvrability and the ability to hover, the helicopter enables the fastest submarine to be overtaken and out-manoeuvred. The hovering capability further permits the use of that well proven instrument of detection and attack, sonar. This precison echo ranging instrument tells the crew commander precisely where to launch his homing torpedo.

The helicopter promises so well for the future that efforts are now being made to provide these versatile machines for our destroyer escorts. Flying from a deck on the stern of a destroyer the helicopter will greatly extend the ships ability to detect and strike.

In addition to the anti-submarine aircraft, the Navy operates the F2H3 Banshee fighter, an all-weather, high altitude, ground support machine. Such aircraft are required at sea to combat the threat posed by an enemy's reconnaissance and strike aircraft. The Banshee is equipped with the heat-seeking Sidewinder missile for this purpose. In addition, close liaison with the Canadian Army keeps the Banshee pilots in touch with modern techniques for ground support, the Banshee having the capability to carry an impressive array of rockets, bombs and cannons for use in this role.

Experience in the past has shown the need to keep the air-arm versatile. With the Navy's ability to translate itself in a short time to the most distant reaches of the seas, our aircraft must have the ability to fulfil a variety of tasks.

The nature of flying from ships underway at sea demands not only that aircraft have special characteristics and great reliability, but that the aircrew maintain a high state of individual training. Because of these requirements, the Navy follows closely the advances in aeronautical technology with the ever present thought that even greater operational results can be achieved through technical achievement.

Many officers and men take a deep interest in the work of the Canadian Aeronautical Institute. I am pleased this is so, and trust that active naval participation will continue and increase. The work of the CAI in fostering a close working relationship between the operators of aircraft and the aircraft designers and manufacturers can only result in better understanding and, in turn, better aircraft for the future.

VICE-ADMIRAL H. S. RAYNER
Chief of the Naval Staff

THE SECOND INTERNATIONAL CONGRESS IN THE AERONAUTICAL SCIENCES

by G/C D. M. Holman

Royal Canadian Air Force

Some two years ago the International Committee of the Aeronautical Sciences held its first International Congress in Spain. It provided a forum where scientists and engineers from many countries could meet each other and could present and discuss papers in aeronautical and related sciences. The second such Congress was held in Zurich, Switzerland, 12th to 16th September, 1960.

The Congress was attended by some 500 delegates from 21 countries. A number of Canadians were there. Among those I met (and possibly the whole Canadian representation) were:

Mr. D. Boyd	Rolls-Royce (President, CAI)
Dr. J. J. Green	CARDE
Dr. H. J. Luckert	Canadair Limited
Dr. C. J. Maiden	CARDE
Dean D. L. Mordell	McGill University
Dr. W. A. Morgan	Dept. of Mines and Technical Surveys
Mr. J. H. Parkin	NRC

Dean Mordell, Dr. Maiden and Dr. Morgan delivered papers.

Excellent accommodation was provided in various hotels throughout the city. Technical meetings were held in two extremely fine lecture halls of the technical high school of Zurich. Except for opening and closing sessions and part of one other, simultaneous sessions were held on different subjects. Simultaneous translation was available (English, French, German) using IBM radio equipment, so that if one wished he could sit in one lecture and tune in the other. Generally speaking, I found the translation adequate but not up to the technical standard of the papers and a bit difficult to follow, particularly due to the time delay in relation to charts and diagrams. Some 60 papers were presented. Copies of these individually or of the complete proceedings are available from the organizers for a price.

The administrative arrangements, set up in a large hall outside the lecture rooms, were very good indeed. They provided such things as travel, accommodation, money changing services, registration, general information, purchase of preprints, purchase of photographs taken from time to time during the Congress, and message handling, using special forms and a couple of large notice boards.

The technical sessions ran from 8.30 in the morning, usually to a bit after 5.00 in the afternoon, with a varying but reasonable lunch break.

On the social side, there was a reception on the Monday by the Mayor of Zurich in the very picturesque Stadthaus, an excursion on the Lake of Zurich on the Wednesday afternoon and a dinner on Friday afternoon. For ladies not attending the sessions, a very comprehensive programme of visits and excursions had been arranged.

On Tuesday, four of the Canadian group took time off to visit the Contraves Company for some very interesting descriptions and demonstrations of their equipment, including anti-aircraft fire control kinetheodolites, computers and a small ground launched missile.

The city of Zurich is clean, friendly and very picturesque, with lovely old buildings along its lake, and waterways lighted at night. The reunions with old friends and the new friendships made were most pleasant. Altogether I found it a most enjoyable and useful interlude which I would be happy to repeat.

Canadian delegation: (l to r) Dean D. L. Mordell, Dr. C. J. Maiden, Mr. D. Boyd (President, CAI), Dr. J. J. Green, Dr. H. J. Luckert, G/C D. M. Holman and Mr. J. H. Parkin.

A MAN HAS FLOWN BY HIS OWN POWER IN 1937†

by Enea Bossi

The Institute has been privileged to receive from Mr. Enea Bossi a brochure, containing an account of his experiments with man-powered flight and a number of drawings, photographs and press-clippings. Unfortunately not all of this material can be reproduced here, but the following is his own account of his work with a few of his photographs and drawings.—Sec.

BRIEF HISTORY OF ENEA BOSSI

Of all the dreams of aeronautical engineers, the most fascinating is human flight. How many laymen and how many scientists have devoted a great deal of time to this problem we shall never know. You will find, even today, many people saying that it is impossible. Sixty years ago no man had ever flown and less than one person in a million would admit that it was a possibility. I heard the same thing when I was in college, even after the Wright Brothers had made actual flights for as long as half an hour, powered with 24 hp. Today they say the same thing about flying by means of human power alone, but it will not be long before sustained flights of 15 to 30 minutes will be accomplished and from then on improvement will be very rapid.

I was living in Milan, Italy, at that time and after I graduated in Physics and Mathematics I started to design my first airplane. My father, who was a very progressive man, notwithstanding the negative advice given by his best friends, decided to finance my idea. This was in 1908.

My first plane was completed in 1909 and I proceeded to test it, first as a glider pulled by an automobile. After a very short but successful takeoff and landing a schoolmate of mine asked to be my passenger. I went up about 50 feet and I started to make a turn (my first one) when my passenger got frightened and took hold of my arms. We crashed! From then on I was more determined than ever to continue my work. I had been in the air no more than 30 seconds, but I was so fascinated that nothing could stop me now.

In 1909 I rebuilt the plane, added a 28 hp engine and after four months of testing I flew a one kilometer circle three times! From then on I made constant progress, and from 1913 to 1915 I was designing, manufacturing and delivering seaplanes to the Italian Navy.

I mention the start of my career in aviation, because it happened when very few people believed that a man could fly, even with the best motor available. Today history repeats itself. Do not be discouraged. Man will fly with his own power. For how long and how far? That depends on how fast we make progress in this particular work. Aeronautical science is complex and only those skilled in this art have a chance to make any serious contribution to it.

†Received 13th October, 1960

HOW I BECAME INTERESTED IN HUMAN FLIGHT

It was in 1935 that I read in a magazine that a man claimed to have built and flown a plane equipped with a 1 hp motor. There was no description, nor a picture of the plane. It was a brief item and I do not recollect the name of the builder. For curiosity's sake I made some calculations to find out if such a flight, no matter how short, would be possible. The results I obtained indicated that, under certain favorable conditions, it could have been a possibility. It was at this point that the idea to tackle the feasibility of man-powered flight came to my mind.

At that time I was connected with a large American manufacturer and, although my office was in Paris, I was constantly traveling in Europe, with frequent trips to the United States. In those days we were still crossing the ocean by boat; it was during these trips that I had time to devote to this project and the more I worked on it, the more it fascinated me.

There were two approaches to the problem: one was to rely completely on calculations; the other was to divide the problem into two parts, each based on certain preliminary experiments, namely,

(a) to build a stand to test the actual traction of the propeller or propellers, when actuated by man-power and for a predetermined period of time, and

(b) to design and build a plane that could fly with the traction obtained in test (a).

Furthermore, a test fixture of this kind would be important in selecting the strongest pilot and also would serve as a means of training, which had to be conducted methodically and scientifically.

As, up to that time, I could not find any reliable results of tests made to measure the power developed by a man on a bicycle, I found it necessary, before starting designing the plane, to find out the traction of propellers of different diameter and different pitch and also to establish the optimum number of pedal revolutions for a sustained effort of at least 1 minute.

In addition it was necessary to carry out some experiments which could prove the feasibility or not of flight by human power.

The first test I made with a well designed primary glider, manned by a very good and very light pilot.

Attached to the frame and in front of the pilot I placed an easily readable scale, from 0 to 30 lb, attached to the tow rope; which consisted of a cord with the two ends connected to 2 feet of rubber to amortize shocks. A professional bicycle rider was to pull the glider. The glider pilot was to watch the scale and the special speedometer connected to one of the wheels. It was important to know at what speed the glider took off. The pull registered on the scale was graphically recorded, but it was not perfectly constant, notwithstanding the rubber cords, and it was therefore necessary to interpret it by taking the mean reading.

The tests were conducted on a wide, seldom used concrete road approaching an airport near Philadelphia, Pennsylvania. Whenever the pilot thought he had sufficient speed to take off, he overcontrolled and the glider would go up 2 or 3 feet, lose speed and land. He finally learned that the takeoff had to be made very gradually. Several flights were made at 2 to 3 feet from the ground, some as long as 400 yards. The tests came to a final end when the pilot made his best flight but broke a wing against a pole on the side of the road. We never expected the plane would go that far, but probably a favorable breeze had helped to sustain the flight longer than expected.

Figure 1

As I stated before, the graphs on the scale gave a picture of what was happening during each test. I learned how many pounds pull a bicycle rider could produce with a bike. Incidentally the gears of the bike were for a maximum speed of 25 mph. At this point I may add that the physical condition of the bicycle rider and atmospheric conditions (wind, temperature and humidity) seemed to have a noticeable effect on the results of each test.

My next problem was to find out if I could take a bicycle, remove the chain going to the rear wheel and, instead, connect the chain to a single propeller (Figure 1) and duplicate the speed and traction equivalent to the results obtained in the previous tests. My assistant and I personally made these experiments. The best speed I obtained was 20 mph, while my assistant reached 23 mph. Probably the speed could have been higher, but the gyroscopic effect of the propeller was so great, to the point of being dangerous, that we decided to run traction tests on a stand designed for the purpose. At this point I realized the necessity for two propellers, instead of one, to avoid the gyroscopic force. Traction measured on the stand proved that a possibility of success

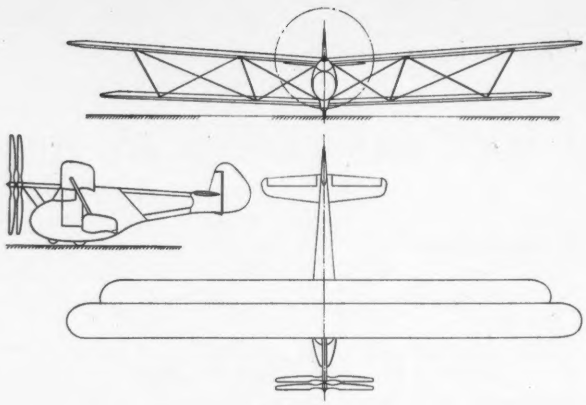


Figure 2

existed, if a plane could be made for a certain weight, surface etc.

The airfoils examined by me were three: NACA F12, NACA 23012 and Gottingen 652. I selected the NACA F12 because of its efficiency. By calculation, the NACA F12 required 0.88 hp, while the NACA 23012 required 0.91 hp and the Gottingen 652 required 0.97 hp. From the previous tests I had conducted I knew that the pilot could develop 1.27 hp for more than a minute, which was sufficient for flying.

After selecting the airfoil, I calculated the diameter and pitch of the propellers. (Which were subsequently changed, several times, improving the performance each time.) I also figured the maximum weight of the plane and the amount of surface necessary to meet the calculated speed and power. It was not easy and it took me some time to obtain the best combination.

At this point I had to decide between a monoplane or a biplane. First I designed a biplane (Figure 2). Then I changed my mind and designed a monoplane (Figure 3). It was a toss-up which would be the better. The main problem was weight, and even today I do not know if someone could do better with a biplane. The total weight is a very important item and, due to the fact that the speed of the Aerocycle is low (20 to 23 mph), the lower drag of a monoplane is not a big factor. (This matter merits further study.)

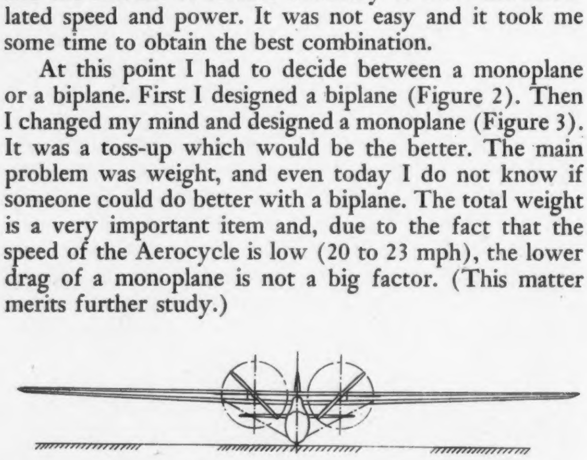


Figure 3

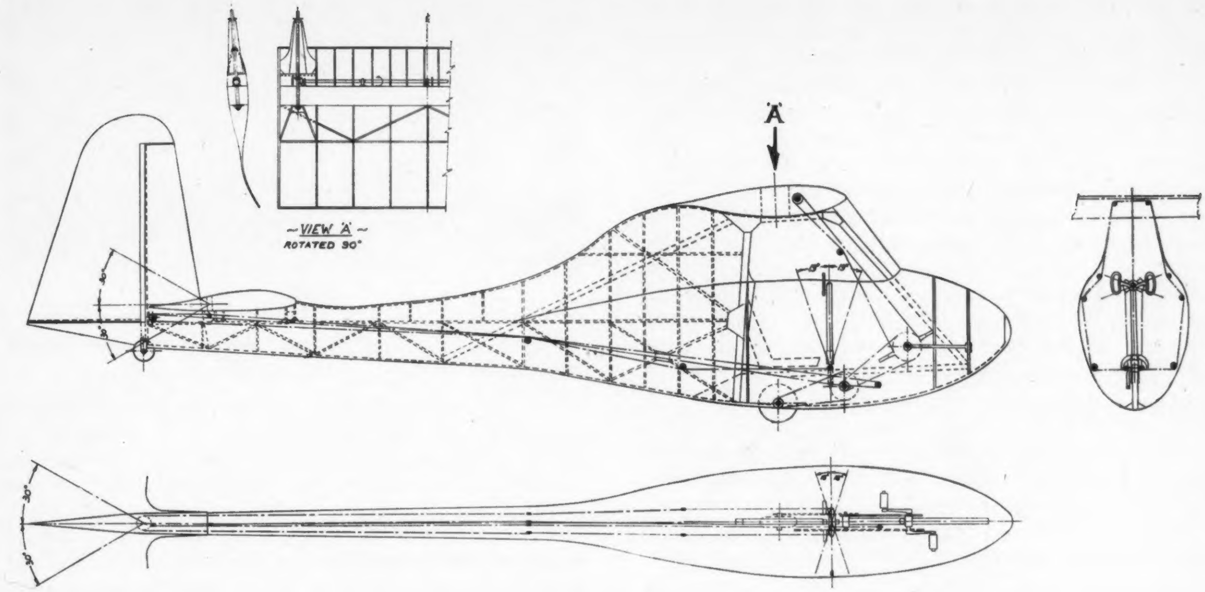


Figure 4

After these calculations, I made the three view drawings and collected all the information of my experiments.

The word "Aerocycle" is a liberal translation, that I coined from the Italian name "Pedaliante" meaning "fly by pedals".

A COMPETITION IN ITALY FOR A MAN-POWERED FLIGHT

At the time I started to work on my Aerocycle there was another incentive to my going ahead with the construction of it. The Italian Government had offered a prize of about $5,000 for a flight of 1 kilometer made by human power. I decided to go to Rome to file the necessary papers with the proper authority, so that I could take part officially in the competition.

Although I was born in Italy, I left that country immediately after the First World War and I had been an American citizen for many years. To my surprise I was told that only Italian citizens could take part in the competition. I consulted my friend, Mr. Bonomi, and we decided that the best thing left to do was to invite newspaper men to witness the tests; which we did. As far as I know, no one took part in the competition.

MOMENT OF DECISION

I was now at the critical moment. Should I have the Aerocycle built? How much would it cost? Fortunately, I had a schoolmate of mine in Italy who was building gliders for the Italian Government – a very intelligent man, a pilot himself and of high integrity. I went to see him in Milan and I told all I had done at that time, and I asked his opinion. He was enthusiastic and eager to build it. He agreed that the possibility of success existed. The price was set and the work went well and without delay.

The weight specified was to be 160 lb with a margin of error of +20 lb. The calculated safety factor was to be 2.0.

The reason for my choice of such a low figure was that at the predicted speed of the plane and at the altitude it was to fly (I was satisfied that tests would never be made above 8 or 10 feet) there would be no danger of a serious accident to the pilot. The Authority in Italy, however, did not agree with me, and the plane had to be reinforced and the weight went up to 220 lb. This penalty was the main reason for the pilot not making longer flights than he did. Figures 4, 5 and 6 show general construction and run of controls.

Now the actual tests started: First we equipped the Aerocycle with two extra wheels, to allow the pilot to taxi until he had familiarized himself with the new type of controls and, at the same time, to train himself. After three long weeks we decided to remove the extra wheels and tow the plane with a rubber cord, so that the pilot could check the flight conditions, including the spoilers, which were something new in a glider. A couple of months went by, bringing modifications to the spoilers, increasing the diameter of the propellers and other minor changes. When everything was ready the pilot was instructed to try to fly by his own power.

On the first day, after a few attempts, the plane actually took off by its own power, and flew 300 feet before landing (Figure 7). We were very happy and thought that in a few weeks, with more training and with more experience, it would be possible to make a sustained flight of a mile or more. Instead a heart-breaking period began. It seemed that the pilot could not, for days, duplicate his first flight. We learned that atmospheric conditions had a lot to do with it. With a weight of 220 lb plus the pilot at 160 lb, we were 40 to 50 lb overweight and therefore above the limit of a sustained flight, unless we

had a pilot in perfect physical condition and favorable atmospheric conditions. Of more than 43 attempts, only half were successful and the longest was ⅝ mile.

I had to stop these most interesting tests because I had spent about $12,000 of my own money and that was more than the limit I had in mind when I started. But I am sure that, with the materials available today, it would be possible to build the same Aerocycle with very little modification, and pilots could accomplish sustained flights of 2 or 3 miles or more. May I say to the man that will design an Aerocycle, that at the breathtaking moment, when he sees the plane a few inches off the ground for a few seconds, he will be repaid for all the work he has done and he will never forget those seconds for the rest of his life.

AFTERTHOUGHTS

If the weight of my Aerocycle had been 160 lb without the pilot, as originally estimated, I am sure that a flight of 3 to 4 miles or more would have been achieved.

Why could I not obtain better results and much longer flights? During the tests I redesigned the propellers several times, increasing the diameter each time and reducing the pitch, until I had no more space because the tips of the propellers were almost touching the fuselage. The propeller thrust increased each time.

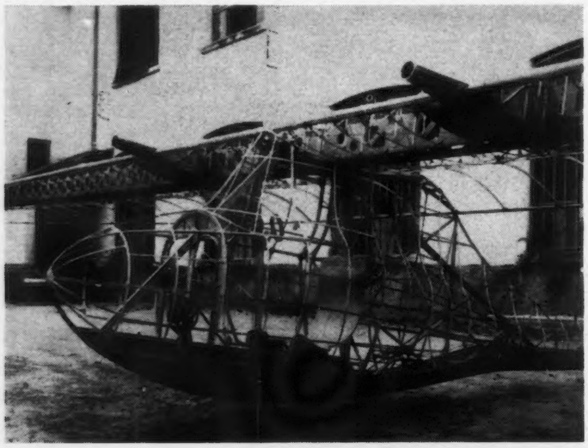


Figure 5

Another cause was the overweight which was due to the Italian equivalent of our CAA in the USA insisting on my increasing the safety factor to almost twice the figure I had used. My point of view was that I could instruct the pilot to fly no higher than 10 to 15 feet, in which case no matter what kind of accident, it could not be serious. This was borne out when the Aerocycle once landed against a tree, without any injury whatsoever to the pilot; a second time the plane landed in a ditch and on its nose, again without a scratch to the pilot.

With regard to weight, I would say that with new materials available today, as compared with 1936, considerable saving of weight could be obtained. The transmission to the propellers, including the chains, could also be made with lighter materials and just as strong. But I am of the opinion that it would be difficult to improve upon the wing loading, aspect ratio and airfoil.

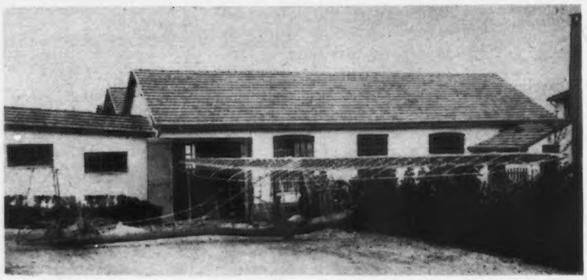


Figure 6

There are, always in my personal opinion, certain MUSTS in order to achieve success:

1. The secret of taking off from the ground is based on having the single wheel connected to the pedals in a proper ratio, because with the propellers alone we were never successful. Furthermore, it is advisable to have one man holding the tip of a wing and running with the Aerocycle, until sufficient speed is obtained for the pilot to control lateral stability. It is also advisable that another man, at the tail, should help the start by pushing for 100 feet or so; this saves a major effort by the pilot. Another way, if possible, is to start on a slightly inclined runway, particularly for the first attempts.

2. It is necessary to have two propellers to avoid the gyroscopic effects, which are dangerous. Tests with a bicycle and a single propeller forced me to this decision.

3. When the Aerocycle is built, ready to be tested, I recommend equipping it with two extra wheels for ground stability, until the pilot has made a good many taxiing tests and familiarized himself with the new type of controls.

4. All tests should be made on a very smooth runway.

To summarize my experience I say first that, if I had to do it again, I would begin by re-calculating to check if the same Aerocycle could be built at not over 160 lb; if not, I would make no attempt to go further.

I would increase the diameter of the propellers; the amount of increase should be determined by laboratory tests measuring the traction with both propellers working together. Such a test is also very important in determining the strongest man and the length of time he can fly. Besides, it is necessary for training purposes.

There is only one thing which I am not sure about, whether it can be improved or not, and that is the use

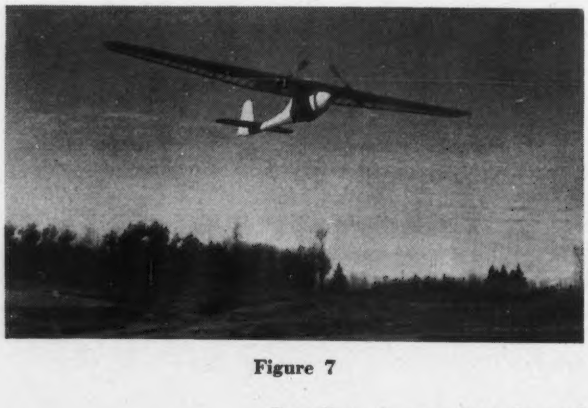


Figure 7

of spoilers. However, due to the type of airfoil I used I would not make any change.

I take the liberty to make some suggestions:

1. When you have designed your Aerocycle, but before you start to build it, put your propeller or propellers on a stand and measure the traction for a continuous period of time, not less than two or three minutes.

2. Check the power necessary to fly your plane and see if you can produce it.

3. My experience favors two propellers of large diameter and rotating at low rpm.

4. The pedals should be connected by chains or other means to the wheel to facilitate takeoff.

5. Preliminary ground tests should be made with three wheels.

If an engineer wants to play safe, before spending lots of time and money, calculating, designing and building an airplane to be flown by human power, I would recommend that he should design and build a stand on wheels (preferably three wheels, two in front and the third at the back) with two propellers rotated by means of pedals similar to a bicycle. This is a very good way to judge the static traction and also the maximum speed obtainable on an airport runway, after the man has been sufficiently trained. The addition of a rudder will give better directional control than steering the third wheel. From these tests the key to designing the plane will emerge.

The problem today is not "Can a man fly by his own power?" but "For how long can a man fly by his own power?".

I hope I have succeeded in giving you a picture of work I have done. It is up to the younger generation of aeronautical engineers to obtain further success, which I sincerely believe possible.

I must add that most of the newspaper reports on this work are not accurate. There are discrepancies in the weight of the plane and of the pilot. The discrepancies are due to modifications introduced from time to time to the Aerocycle, as well as changes of pilot. The information given by me in this report is correct and refers to the time the pilot, Mr. Casco, made his best flights.

Because testing a human-powered plane must be a slow and progressive procedure, publicity should be avoided until it is possible to repeat successful performances. People are easy to condemn your efforts if you do not take off the ground and fly the very first time you try. Do not be impatient, but keep the newspapers away until you can duplicate at least a takeoff by human power alone. If you cannot avoid witnesses, explain before you start the reason of the test and what you are trying to do; but if you are alone with your engineers and the pilot without unnecessary people around, you will be able to work much better.

Unfortunately, the great majority of men that have built planes to be flown by human power were not aeronautical engineers; hence the failures. Only the combination of aerodynamics, stress analysis, weight and the actual thrust obtained from a propeller or propellers turned by human power can predict success or not. In fact, another factor should be added, the pilot.

It is therefore an extremely complex problem, but very interesting.

I have the complete manufacturing drawings of my Aerocycle, but the "ozalids" are now quite discoloured and only a draftsman with patience could go over the lines; in which case they could be reproduced again.

RELIABILITY-MAINTAINABILITY ENGINEERING OF AIRCRAFT, WEAPON, AND ELECTRONIC SUPPORT SYSTEMS†

by C. I. Soucy*

Air Materiel Command, RCAF

INTRODUCTION

It is proposed to assess the progress in reliability-maintainability engineering since a previous 1957 paper to the Institute[1], to evaluate the state of the art and current levels: to hazard some speculations on future needs and goals and on what can be done to assure or hasten their attainment.

It will be assumed that you as user, both military and civilian, or producer of aircraft, weapon and their ground support systems, are convinced of the growing need for increased reliability and maintainability, which we can consider together as "dependability". Nowadays, nearly every product advertisement makes a claim for merit in this field. If, in Canada, we have had no explicit Department of National Defence or individual Service directives stressing this need, as the United States parallel agencies have had since 1951, it is probably because it is generally assumed – even if, in the writer's opinion, mistakenly – that the need is self evident. One public appeal for industry's support and understanding of the military need was made by the Chairman of the Chiefs of Staff, Major General Foulkes, in 1957, to the Canadian Convention of the Institute of Radio Engineers at Toronto[2].

The word "reliability" is seldom employed by itself in this discussion. Since, as a probability of no failure, reliability has been defined quantitatively in terms of the mean time between failures, it has been necessary, in order to evaluate what might be called "dependability", to consider the inseparable accompanying requirements for maintainability as well. It is unfortunate that the combined reliability-maintainability requirements are seldom considered by the same design organization or covered in the same specification. This unfortunate separation of requirements has resulted in retarding the progress in design for maintainability and has delayed progress in defining the latter characteristic quantitatively.

---

†Paper read at the Annual General Meeting of the C.A.I. in Ottawa on the 25th May, 1960.

*Chief of Telecommunications Engineering Standards

You are referred to an earlier paper[1] for consideration of the inadequacy of rating equipment and system dependability based solely on failure rate or reliability data and disregarding down-time dependent on maintainability characteristics. Another factor "availability", that is, per cent operating time relative to operating plus down-time for all maintenance, provides a combined rating of reliability and maintainability.

The most concrete evidence of the need for reliability-maintainability assurance programs by the Armed Services is shown in the specification requirements that are now being introduced. In 1956, the RCAF first applied reliability-maintainability requirements with priority over other performance characteristics in selecting a new UHF airborne radio set, the AN/ARC-552. This set appears to be realizing the predictions made for its improved performance in this area, including a goal of 25 to 1 improvement in reliability. The first "system" reliability specification of the RCAF was written for the electronic system of the CF-105 (Arrow) aircraft but, unfortunately, its effectiveness was not proven due to cancellation of this program.

Early approaches to reliability engineering of electronic equipment concentrated on what appeared to be the obvious solution by improving component parts. A better perspective and knowledge of controlling factors, which will be examined briefly later, led to an "equipment" approach[3] and later to "system" treatment and "man-equipment-system" analysis and, finally, in this age of satellites and space vehicles, to the comprehensive "man-equipment-environment-system" view. It has been estimated that reliability and related design problems are 100 times more difficult for guided missiles than for aircraft electronics, and the space vehicle problem will be more difficult by at least an order of magnitude.

PYRAMIDING GROWTH OF SYSTEMS

Figure 1 shows how the growth of complexity of individual military electronic equipment and the electronic portions of aircraft and weapons systems continues to accelerate[3, 4]. This amazing climb will surely continue due to pressure from requirements for increased per-

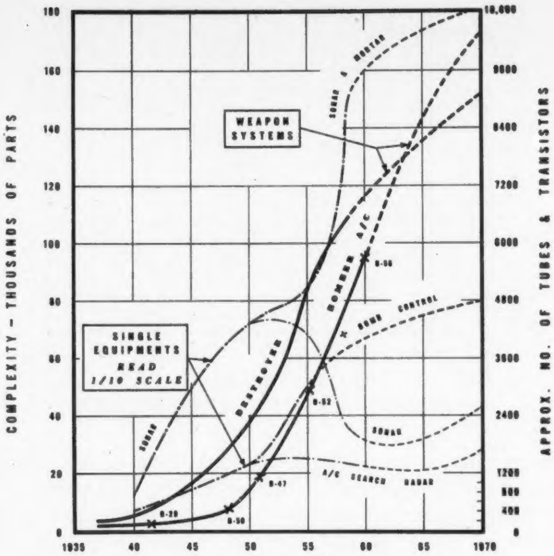


Figure 1
Increasing complexity of military electronics

formance. In the past, no awareness of the alarming trend to decreasing system reliability (which has only recently reversed, as will be shown later) has operated to retard the heedless pyramiding of complexity. From 1950 on, it is observed that some equipments, such as the sonar and radar examples in the curves, have been simplified in operational requirements and reduced in complexity, but others of the same functional types now have added operational functions and complexity. Increasing complexity will likely be resorted to in meeting the fantastic needs of intercontinental ballistic missiles and space vehicles; indeed, the filling of this need will be facilitated by the tremendous possibilities in size reduction of parts promised in current micro-miniaturization developments.

The naval destroyer and bomber aircraft examples on this chart by no means represent the largest current weapon and electronic support systems. Several missiles have reached a complexity of 1.5 million parts, including 3000 tubes in the case of the Nike-Hercules. The Nike-Zeus will be much more complex. The BMEWS (or Ballistic Missile Electronic Warning System) electronic-data-processing system, now covered by 700 million dollars in contracts, is said to make the SAGE and similar electronic support systems look simple. The BMEWS with a handling capacity of five times that of the IBM-704 Computer will have to process upwards of 40,000 messages in a 15 minute alert period.

The vast SAGE (Semi Automatic Ground Environment) System, costing the United States over one billion dollars and 400 million dollars in operating costs per year, which will integrate missile and interceptor defence has, as its major element, AN/FSQ-7 Computers each employing about 1.5 million component parts, including 58,500 tubes.

The costs of modern military aircraft and weapons are becoming as stupendous as their complexity. Aircraft such as the B-58 (Hustler) Bomber, at 26.7 million dollars each, are correctly rated worth more than their weight in gold by President Eisenhower. His estimate of the cost on the firing line of 35 million dollars each – when the ground support system for the 2 million dollar Atlas ICBM is included – illustrates our tendency to overlook the less glamorous ground support systems which will account for 85% of the US defence budget for missiles.

According to a recent Electronics Industries Association report, ⅓ of the US defence budget is for electronics, and this will rise in future. In missiles, the percentage of the cost is between 48% and 70%[5, 6], and the dependence of their system reliability on electronics is about 40%; in modern fighter and bomber aircraft the cost is rising to 54%[6]. The increasing dependence of aircraft and weapons upon electronics is illustrated in the Figure 2 photograph of the "flying radome" otherwise identified as the Grumman WF-2 Tracer aircraft used by the US Navy.

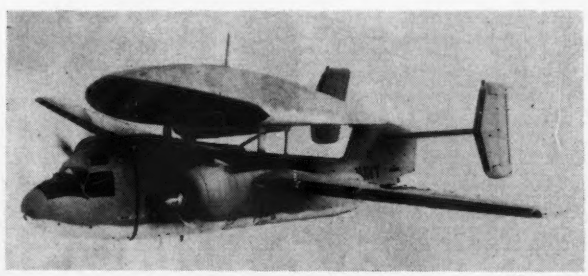
In addition to a tremendous future increase in complexity of military systems, we can look forward to the existence of thousands of satellites circling our planet. These will report weather, detect missiles or carry out other reconnaissance, provide high accuracy navigation fixes and – probably most important – will extend the possibilities for volume of communications by a factor of perhaps even 10,000 to 1.

These space vehicles and their communication needs will greatly magnify the demands for reliability as well as for other improvements in performance. We will have to exceed the performance demonstrated in the proven radio transmission to the sun and back (in a 17 minute trip at the speed of light) for communication over the greater distances to the planets. To assume 99% probability of success in a 68 month trip to Mars and back, the mean time to failure for the vehicle system would have to be 600,000 hours or 68 years[7].

The 1000 mile orbit typical of the Explorer satellite will have to be multiplied by factors of 100 to reach the moon, and of 10,000 to 100,000 for the planets and the sun. The power for communication will have to be raised up to 10 billion times or by 100 decibels.

The "New World" environment for aircraft and weapons will increase reliability and design difficulties due to new and increased environmental stresses, which have been discussed in many previous papers, and are illustrated in Figures 3 and 4[8].

As others, besides, have observed before[1, 9], we need an extension of the new way of thinking at both engineering and management levels about reliability-maintainability matters.



Grumman

Figure 2
US Navy's Grumman WF-2 Tracer (72.5 ft x 43.5 ft) with airfoil-shaped radome (20 ft x 30 ft)

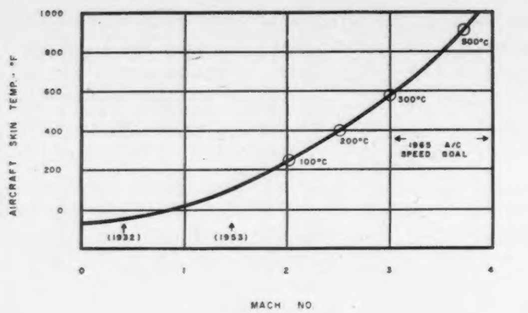


Figure 3
Trend toward higher aircraft speed and temperature

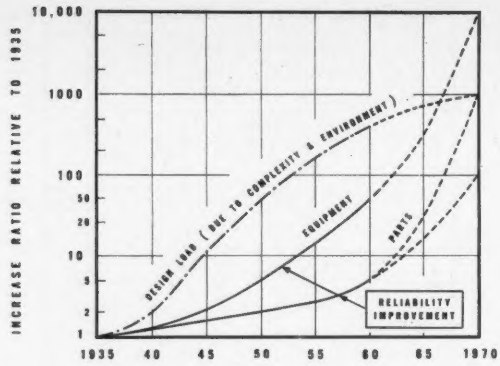


Figure 5
Increasing design load vs reliability improvement

PROGRESS AND FUTURE GOALS IN DEPENDABILITY

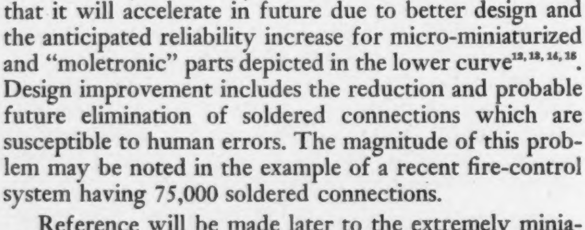
In previous papers[1, 9, 10] attention has been drawn to the alarming trend to a deficit between the increasing design load indicated in Figure 5 and the relatively slow rate of improvement in reliability of electronic parts. Relative to 1935, the design load difficulty, compounded of increased complexity (from Figure 1) and increased environmental stresses, has increased by 600 times in 1960, with a corresponding average component part improvement of only about 5 to 1[9].

A more optimistic report than that presented in 1957[1] can now be made, as shown in the middle curve of Figure 5 labelled "Equipment Reliability Improvement". The increase has been more rapid than could be predicted then: 1.6 up to 5 to 1 for USAF's airborne equipment in the last 2 to 3 years in one estimate[11], and 10 to 1 for the last 10 years in another[12]. It is estimated that it will accelerate in future due to better design and the anticipated reliability increase for micro-miniaturized and "moletronic" parts depicted in the lower curve[12, 13, 14, 15]. Design improvement includes the reduction and probable future elimination of soldered connections which are susceptible to human errors. The magnitude of this problem may be noted in the example of a recent fire-control system having 75,000 soldered connections.

Reference will be made later to the extremely miniaturized parts arising from a break-through in the development of solid-state parts. Here, we are concerned for the moment with the data shown in Figure 6 indicating that volume reductions since 1935 of over seven orders of magnitude are anticipated. This will permit the increased packaging density needed to accommodate the increases in complexity and the reductions in size and weight required for missiles and space vehicles. Failure rate reductions up to 1000 to 1 are being predicted[14], but, while the feasibility of large size reductions has been demonstrated experimentally, it is too early yet to guarantee the reliability of the production product or that part costs will not remain at a very high level. Reliability predictions should be treated with caution at present.

As Figure 7 shows clearly, the reductions in volume and weight of military equipment are very much less than proportional to the reductions in size of component parts. Besides requiring extra weight and space to provide for high-altitude pressurization and cooling, airborne sets tend to increase in complexity, output power and other performance characteristics. Therefore, they have achieved still less miniaturization than the pack-sets. Preliminary designs of the AN/PRC-36 Helmet Radio and the Modulator Sub-Assembly of the AN/TCC-26 Time Division Multiplex equipment confirm that 10 to 1 size reductions will be achieved using micro-modules.

Figure 8 shows the equipment reliability index (mean time to failure[8, 12, 13]), and also the maintainability index (inverse of mean time to locate and repair faults). The



Martinez

Figure 4
Future aircraft and GM environmental factors

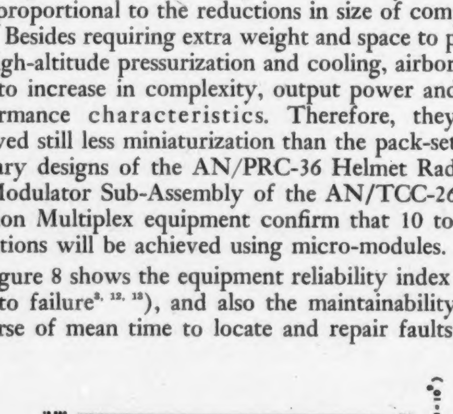


Figure 6
Trend toward electronics miniaturization

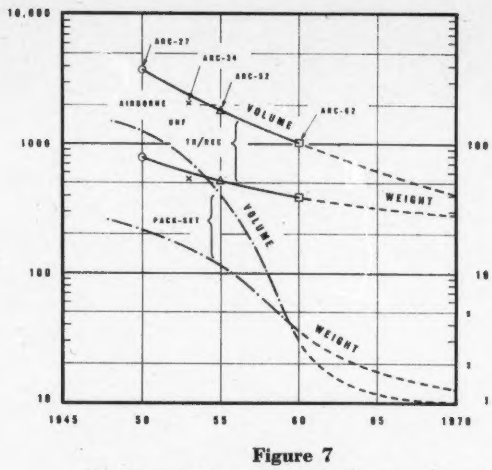


Figure 7
Miniaturization trend in military radio sets

latter is based mostly on an estimate by Mr. M. V. Ratynski[16]. It is evident that both indices have declined until recently, due to increasing complexity and environmental stress. Projecting anticipated improvements shown in Figure 5, this chart indicates that the worst stage (which justified past forebodings) is now over and, in the next 5 to 10 years, our much more complex equipment and systems may perhaps regain the relatively low levels of reliability and maintainability of the simple pre-war black boxes.

Will this be good enough? Probably yes, for those systems that don't follow the complexity-increase trend. A system such as an aircraft-guidance one, with a mean time to failure of only 25 hours now[18], would only have to be improved 30 times to serve for a 730-hour return trip to the moon; but, for a reasonable minimum 10,000-hour life in communications or reconnaissance satellites, the 400 to 1 improvement needed may take until 1970 to achieve unless redundancy is employed. One of the most troublesome component parts for such long mission periods is the microwave electronic tube needed for radio communication, since this has not yet been designed for long life. A 1958 USAF estimate for the probability of a 4 million dollar missile impacting its pay-load on the

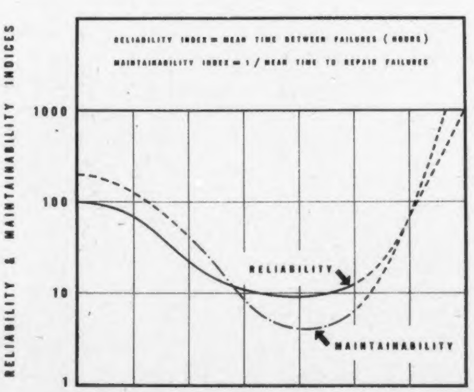


Figure 8
Decline and rise of military electronics dependability

moon was 70%. So far, no one has ventured a prediction on the possibilities of a return trip. The prospects for obtaining life insurance for space travellers do not look bright for some years beyond the present reach of our crystal ball, and volunteers will need unusual motivation or some compensating experience values to warrant acceptance of the hazards involved.

The writer's own estimate is that, for less complex military equipment, we need reliability improvements of from 10 to 100 times, and for space vehicles and complex missiles up to 10,000 to 1, a figure confirmed by Dr. R. S. Roberson of North American Aviation's Autonetics Division[7]. Organization, effort and the aforementioned new way of thinking are necessary to attain this fantastic goal. We may be encouraged by noting that the predicted reliability of the trans-Atlantic telephone cable system is nearly a million times better than that of the poorest mobile system in wartime military use[8]. In case these comments and the enthusiastic newspaper and TV reporting of missile failures at Cape Canaveral and for the controversial Bomarc-B have led you to suspect all missiles, encouragement may be derived from reports on reliabilities of 80% in interception for the Nike-Hercules, 93% for troop-fired Corporals, and 95% for 41 firings of the Redstone between 1953 and 1958[17].

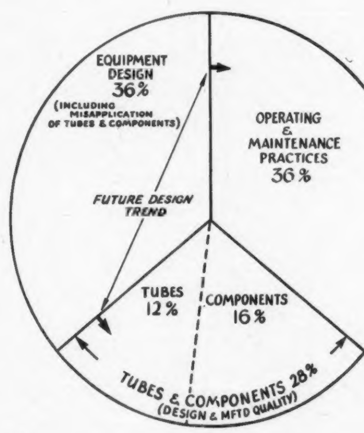


Figure 9
Rough analysis of control factors for failures in military electronic equipment

The military reliability programme has had a considerable impact on the industrial electronics field. One evidence of this is the raising of warranties on equipment from previous 90-day periods to from a minimum of one up to five years.

CONTROL FACTORS

With fantastic reliability improvements needed in the future, we cannot afford to be misled by half-analyzed or misinterpreted failure data, as was a common situation a few years ago.

A review of previously presented analyses of failures claimed[1, 2] will not be repeated here but, from the conclusions thereof, illustrated in Figure 9[1], we can observe that tubes and other parts, in the 1955 state of the art, controlled about one-third of equipment failures, and

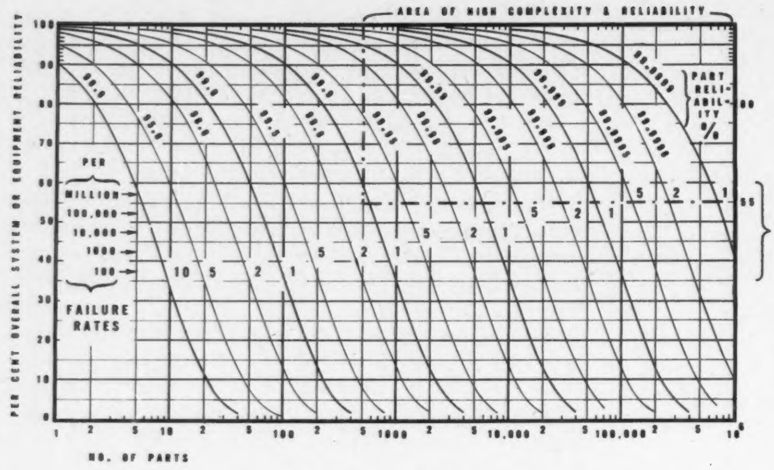


Figure 10
System reliability vs parts and part reliability

that over-all equipment and system design were capable of being increased from one-third control to make the design more impervious to deterioration of parts and to unfavourable operating and maintenance practices. The common factor in all causes of unreliability is human error, whether it occurs in the original design, fabrication, inspection, maintenance or operating use.

The mathematical formula for reliability:

$$R = 100e\frac{-nt}{T} \qquad (1)$$

is presented to show that reliability declines exponentially with time (t), the number of independent parts (n) or complexity, and the rate of failure ($1/T$) of the parts, where T is the mean time between failures, $e = 2.7128$ (base of natural logarithms).

From this equation, Figure 10, showing the relationship between part and system reliability, is derived. Unlike the usual published chart limited to only a few hundred parts, this one covers system complexity up to one million parts and part failures as low as one per million. As examples of its use: If we want a missile system having an 80% probability of success, and have parts with only an average reliability of 99.9% (or failures limited to 1 per 1000), the limiting or critical complexity will be 110 parts; if, say, future parts were improved fantastically to have only 1 failure per million (or 99.9999% reliability), a missile having one million parts could attain the rather low system reliability of 40% without employing redundancy.

Since the over-all system reliability is a product of the individual part reliabilities, it is obvious that simplification is a desirable goal. However, it is attainable only through more mature design, and is generally impeded by increasing demands for greater versatility and precision in performance.

The reliability factor model presented below[18] is included not for its mathematical value but to help clarify the relationships between reliability and quality control, and also between various phases of reliability engineering, beginning with the "intrinsic" value dependent upon the parts used and the quantities of them, progressing to the "inherent" reliability of the manufactured product and thence to the final use or "operational" reliability.

$$R_o = R_I \times K_D \times K_M \times K_U \times K_{OM} = R_I \times K_{OM} \qquad (2)$$

where:

R_o = Operational reliability.

R_i = Intrinsic reliability.

K_D, K_M, K_U, K_{OM} are modifying factors for design, manufacturing and quality control, unknown influences, or operating-maintenance practices, all of which, in general, tend to degrade the reliability below its intrinsic value.

R_I = Inherent reliability of manufactured product

It is unfortunate that two official reliability documents that are widely used as guides, namely the AGREE Report[19] and MIL-STD-441[20] present a confusing reliability model, because modifying "factors" are not distinguished from "reliabilities" at various phases in the cycle of design, manufacture and use.

The cost-trade-off approach to assessing reliability-maintainability is becoming recognized by management[1, 9, 21, 22, 23, 24]. With the rise of complexity and increases up to 100 to 1 in cost of some of the new "breakthrough" parts, costs of military weapons are rising to prohibitive values as witnessed by project cancellations by Canada, the USA and Britain. This economic pressure to attain "value" for our expenditures should provide an incentive for reliability and maintainability assurance programmes. The economic analysis is simplified in the case of missiles where every failure increases the cost of the remaining successful product. The relationship between cost and reliability versus reliability effort and funds, for various reliability skills of the producer, is disclosed in Figure 11, taken from the report of Dr. Erick Pieruschka whose analysis indicates the small possibility of spending too much on an effective reliability programme[24].

Many other Services besides the RCAF have concluded that neither a reliability nor even a wider dependability programme encompass all objectives in assuring a satisfactory product. Air Materiel Command's "Project MATURE"[1] is intended to achieve "mature" equipment that is[9]:

M – Maintainable
A – Achievable, i.e. designable and producible
T – Tried and tested
U – Usable
R – Reliable
E – Economical

Such a programme is very similar to the "Value Engineering" of the US Navy, covered by Military Specification MIL-V-19858 (SHIPS) and to the "Value Assurance" of the General Electric Company, or the "Product Assurance" concepts of RCA and the Hughes Aircraft Company.

NEW TECHNIQUES IN DESIGN AND PRODUCTION

A review of the new techniques developed and in use that promise improvements in reliability and maintainability through more mature design and better production methods would be a large field in itself. The best guide manual for designers, of several available, is one prepared by the US Navy Bureau of Ordnance[25]. The most important areas can be summarized under ten headings as shown below.

(1) *Simplification* of operational requirements and basic equipment and system design therefor,

(2) *Selection* and testing of best available parts,

(3) *Derating* of parts with respect to nominal ratings, employing suitable safety factors or, preferably, safety margins based on tests to destruction,

(4) *Prediction* study of reliability and maintainability factors of system,

(5) *Environmental* control for, or isolation and protection of parts, based on knowledge of environment,

(6) *Circuit design* based on mature engineering, providing circuit tolerance for deterioration in performance and electrical values of parts and tubes,

(7) *Human engineering* to assure fitting of human users into system and to provide ease of operation and maintenance,

(8) *Use of redundancy* in complex systems when parts do not have required intrinsic reliability,

(9) *Quality control* and process control improvement to obtain highest inherent reliability in manufactured product, and

(10) *Failure studies* providing feed-back of failure data from the field, analysis and application in product improvement.

Simplification

This is not a cure-all and can be over-stressed. We cannot go back to the "good old days", because greater precision, speed, range, output etc are now being demanded by operational requirements; however, superfluous requirements can be eliminated. Complexity has been reduced almost 2 to 1 in some designs by greater maturity of the design; however even this is a small gain in comparison with the rising growth of system complexity.

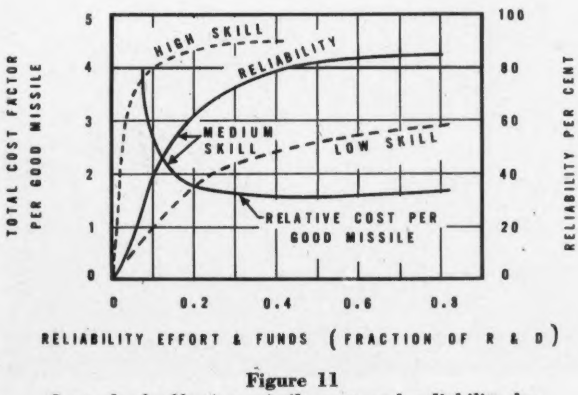
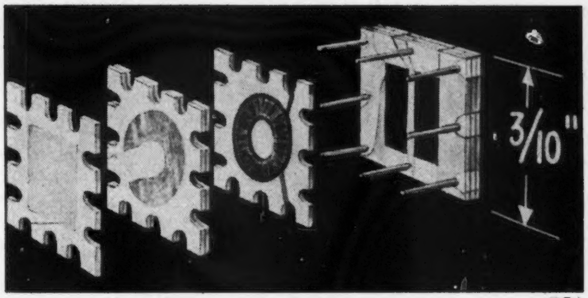


Figure 11
Control of effective missile cost and reliability by reliability control effort and funds



RCA

Figure 12
Exploded view of micro-module

Miniaturization

Miniaturization of component parts is motivated not only by an urgent need to reduce space and weight radically but to achieve operational and maintenance simplicity, to provide better, more reliable parts and to eliminate troublesome soldered connections. The four types of miniaturization include:

(1) Conventionally made miniature size parts, such as transistors now in use,

(2) Two-dimensional individual parts applied mostly as thin films on wafer substrates to form tiny three-dimensional modules as in the RCA micro-modules, illustrated in Figure 12,

(3) Directly-integrated deposition and attachment of individual parts on a single substrate, as in Diamond Fuze Laboratory modules, and

(4) Molecular electronics or "Moletronics" employing solid circuits composed of solid-state materials and attaining even greater stacking factors as shown in Figure 6.

It may be noted that some so-called miniature parts, such as transistors, use only one-thousandth of their volume for the useful portion – the rest being housing, connection and supports. Moletronics, or solid-state modules, under development by Westinghouse and other firms, are expected to find initial application in space vehicles and missiles[26]. These micro-modules, illustrated in Figure 12, are not merely new component "parts"; they are modules of the "equipment" design also, and represent improvements in both areas. In aircraft and ground equipment we may expect some conservative hesitation in accepting these new devices until their predicted greater reliabilities are proven in production. Then, new types of connectors miniaturized in form, and replacing soldered connections by more positive mechanical attachment, are likely to become the most critical element. (One is reminded of the cynical label for a connector as "an unreliable method of connecting two sources of trouble together".)

SOLID-STATE DEVICES vs TUBES

The search for smaller and more reliable parts has led to extensive use of magnetic devices and transistors, diodes and other solid-state devices. The enhancement of reliability in military equipment through the use of transistors is not yet extensively documented, but is reported as 10 to 1 in the case of the computer for the Titan ICBM. The prospects of eliminating the tempera-

ture limitations for transistors and diodes appear promising with new materials such as silicon carbide, gallium arsenide and several inter-metallic compounds. At the same time, we are having a virtual renaissance in tube developments with tiny stacked ceramic tubes and metal-cased "Nuvistor" tubes, and cold-cathode tubes assuring longer life, ruggedness, high-temperature operation and lower power consumption, proving that tubes, by no means, are passé. The trend to transistors is clear, with 30% of the 1960 production of military electronic equipment transistorized, according to an Electronic Industries Association report[6] and predicted as 85% for 1968.

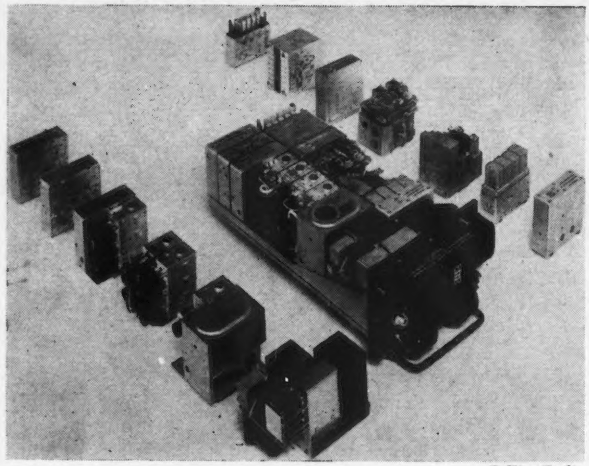
TESTING LOW-FAILURE-RATE PARTS

Apart from tubes and micro-modular assemblies, current reliability goals for electronic parts are 0.01% to 0.001% failures per 1000 hours, representing a maximum of 100 to 1 improvement[15] over parts in World War II equipment. Failures as low as this (1 in 100,000) pose a very difficult testing problem, since quantities of samples and time required for testing to assure statistical validity are not practicable. This problem is being faced by both Canadian and US Military Agencies[27]. New statistical testing procedures to minimize testing effort have been proposed[28] and also use of tests to destruction[1, 18, 29], to determine modes of failure, combined with reliance on engineering judgment. The case of the Atlantic Cable System illustrates the problem. For 90% probability of no failure for 20 years, the part failure rate must be less than 1 per 1,000,000 per year for the 6600 part system. This requirement would take 400 years of testing to verify. Operation in October, 1958, had so far verified only that the failures were less than 1 in 10,000[30]. The achievements in design, production and quality control in this project and the related data should be referred to by all equipment designers seeking guidance and proof of possibilities for military equipment, weapons and space vehicles.

DERATING AND ENVIRONMENTAL PROTECTION

In Figures 8 and 9 of a previous paper[1] in the Canadian Aeronautical Journal, the effects of derating, or operation of electronic components below nominal voltage or power ratings, in reducing failure rates, or in compensating for operation at higher temperatures, were illustrated. In some military electronic parts there is a greater need for derating than for others, because the military specifications for these have permitted operating stress level ratings which are unreasonably high and correspond to excessive failure rates. This fact has not been generally recognized.

The control of vibration and shock stresses applied to parts has been fairly well mastered, but only recently has thermal engineering been applied to remove heat from heat-dissipating parts such as tubes and resistors and to isolate other still more heat-sensitive parts. More effective cooling, including use of heat-reducing tube shields, has reduced failures from 10 to 2 times in some equipment[8]. New devices to effect cooling electronically by a reverse thermo-electric (Peltier) effect are already commercially available and can reduce temperatures 60°C by spot cooling.



Collins Radio

Figure 13
RCAF AN/ARC-522 airborne UHF radio set and modules

DESIGN FOR MAINTAINABILITY

Notable advances have been made in designing equipment for maintainability[9, 31] and in applying therein new concepts of human engineering. Studies have been carried out to determine the optimum extent for carrying out modularization[28, 32] for effective cooling, easy testing, accessibility and ease of replacement of failed parts. A US Bureau of Standards study[33] of airborne equipment procurement cost shows little variation for modules using from 10 to 80 parts, but the Collins Radio study for USAF on modular design of the AN/GRC-27 ground UHF Radio Set indicates a minimum initial-plus-maintenance cost per year with 20 to 50 parts. The RCAF AN/ARC-552 airborne UHF Radio Set, shown in Figure 13, has 13 plug-in modules besides the chassis, case, and mounting. The AN/GPN-T2 GCA Trainer Console, shown in Figure 14, uses sliding-drawer and hinged-panel construction plus plug-in modules to promote maintainability.

Figure 14
AN/GPN-T2 GCA trainer console

REDUNDANCY

Aeronautical engineers will be interested to note that Leonardo da Vinci first envisioned a redundant element to provide a fail-safe element in a flying machine. In his famous notebook he wrote about 450 years ago:

> "In constructing wings one should make one cord to bear the strain and a looser one in the same position so that if one breaks under the strain the other is in a position to serve the same function".

Nature has demonstrated a recognition of how redundancy contributes to reliability by endowing man and other creatures with duplicate limbs, eyes, ears and other features. Of course these pairs provide other operational features besides redundancy.

Figure 15 indicates that, whereas the connection of parts in series reduces reliability according to the power law, as previously discussed, their operation in parallel can increase reliability very considerably. An example relating to guided missiles which was presented in testimony to Congress by the US Secretary of Defense will serve to illustrate the chart. It was assumed that three enemy ICBM firings would be necessary for a 95% probability of destroying a "soft" US missile base. Working back on the chart, we see that a single one would have a much lower reliability, 63%. Use of redundancy in equipment design imposes a penalty in cost, weight or space, but provides a means of attaining a higher reliability, when parts of insufficiently low failure rate must be used in a complex equipment.

RELIABILITY AND MAINTAINABILITY ANALYSIS AND PREDICTION

Several useful papers have been published on the techniques of reliability prediction and reporting equipment and part failure data. A revised edition of the Stress Analysis Report prepared by RCA for guidance of designers may be made available soon under a sponsoring Military contract[34]. For reasons previously discussed, the quantitative treatment of maintainability has been examined by only a few specialists[35, 36]. As an aid in comparing equipment designs and evaluating progress in maintainability, a recent paper has outlined a profile analysis technique for assigning quantitative ratings for subjective judgments on the main contributing design features[36].

QUALITY CONTROL

For a consideration of the relationship between reliability-maintainability control and quality control that cannot be presented here, you are referred to another paper by the speaker and Mr. H. H. Keefe of the Royal Canadian Navy[18]. Recent reports[37] cover some startling results in reducing human errors in assembly lines by the use of slides showing the operator TV-like pictures on a screen with accompanying tape recordings explaining the steps of work to be carried out. In a Hughes Aircraft Company missile plant, soldering faults were reduced from a rate of 6 to 13 per chassis to 0.06 after 10 months – a reduction of 99%. Nearly every operator can, in a short period, sometimes one day, reach 80% to 100% of the desired performance standard where, using ordinary production and inspection methods, the best experienced operators could reach only 50% to 60% after several months.

In this survey covering many facets, it is not possible to do justice to the contribution of quality control in production. The effectiveness of a rigorous quality-control program in assuring the performance of electronic component parts in the trans-Atlantic cable system, whose reliability far exceeds that attained in any military system, is an example of what can be done if sufficient effort and costs for control are provided for[30]. Simple amplifier tubes used are said to cost $1,500 each from a production using only one out of each six produced. This is because of the great process and quality control effort and pre-use 5000 hour period of individual proving test.

Not only the design but the production of military equipment is capable of large improvements. It cannot be contended that the effort and the cost are not justified for military equipment. A breakdown of the Atlantic telephone cable may cost one-quarter of a million dollars for raising and repair, and cause a large loss of revenue, but failures in weapons worth from 1 to 20 millions are no more tolerable. For successful interplanetary flight, we shall have to equal or surpass the reliability of

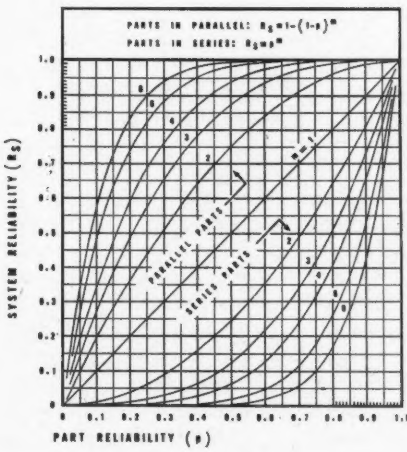


Figure 15

System reliability with *m* series or *m* parallel redundant parts

the Atlantic cable, which is about 10,000 times better than the best military fixed-ground communications system of equal complexity[2]; and this will require, not only greatly improved design, but also a consistency in production that ordinary methods do not assure. There are no emergency landing fields in space, and, if only one failure occurs, blast-off may be the point of no return!

HUMAN FACTORS AND THE MAN-EQUIPMENT-ENVIRONMENT SYSTEM

An important member of the reliability-maintainability engineering term is the human-factors specialist – a combination of an applied psychologist and system engineer. The most effective and reliable systems can

be devised only by making the best use of the human operators. This applies not only in the military field, but even more critically so in the coming field of space travel.

Man-machine control systems are becoming increasingly more complex and of greater importance in modern aircraft and ground networks (electronic support systems) and in radar and computing systems such as SAGE. However, some designers tend to be distracted from a proper interest in the design philosophy of these man-machine systems[38] because of an increasing trend to supersede the man by an electronic computer or an automatic control device. Here, as in other human engineering fields, electronic system design must be combined with the application of engineering psychology. With the addition of high-speed computers and electronically-actuated automatic control mechanisms in the system, the response speed and handling capabilities of the man in the system are readily exceeded. The analysis of missile system failures, revealing at least 25% to 37% as due to human errors, shows clearly the need for simplifying the task of the operator and maintenance technician[38]. At the speed of jet aircraft and space vehicles, unaided human reactions are too slow and inaccurate. It may be surprising to note the opinion of several experts that, in spite of his limitations, the addition of a human being to a space vehicle may improve its reliability and economy by as much as 70%, despite a weight penalty of 5% or 10%[39]. However, for space vehicles, one of the most serious limitations to man's reliability is that his period of vigilance and problem-solving proficiency cannot be extended much beyond twenty consecutive hours[40].

A good survey of this field with many references can be found in H. P. Birmingham's paper[41]. The low precision and high variability of the human are the despair of the mathematical systems analyst who conceives of the human operator as a servo-element who "through learning . . . modifies his transfer function and alters his gains . . . in the direction of optimizing the performance of the man-machine system as it is communicated to him through the displays"[38]. Translated, this means that man is an adaptable though unpredictable animal!

Although this versatility of the human, and his range of acuity in perception, can be used to reduce the weight of a man-machine system, and provide invulnerability to electronic jamming to which alternative electronic reception devices are susceptible, there are limitations in human response both in time (250 milli-seconds are required for effecting choices in action), in reproducability, and in his limited effector control of the rest of the system, since this is limited to muscular action of very variable performance.

The followers of the experts in cybernetics and information theory such as Norbert Wiener and Claude Shannon, treat the human link as a source of information, an error detector, a channel for the flow of information or a receiver of information. His inadequacies as an information channel caused one analyst to characterize him as a "bottle-neck" with a narrow bandwidth, a high noise level, an optimum transmission of about 25 bits of information per second and a limited span of absolute judgment who can think about only 100 bits of information at one time. The result of this is that voice-communication systems capable of transmitting 10^4 to 10^6 bits of information per second are over-designed 400 to 1 for utilization of the human element. If this disparagement isn't enough, Miller also points out that man is expensive to maintain and must sleep eight hours out of twenty-four, but admits his unequalled facility in understanding or translating data[42]. Another analyst credits man with a high visual perception capacity of 4 million bits per second, and points out his remarkable ability to scan incoming information rapidly and to discard what is irrelevant. It may also be noted that, in a space the size of a grapefruit, man's brain can store 10,000 times as much data as the largest present-day computer[43], and has a much smaller power requirement and heat dissipation even compared with a modern transistorized version. The human brain, according to John von Neumann, also has the facility, which we have not yet learned to use in electronic computers and data memory cells, of employing the redundancy of thousands of cells of low individual reliability to achieve a high system reliability[13].

RELIABILITY AND MINIATURIZATION IN NATURE

If we are inclined to feel conceited about our far-from-inconsequential progress in electronic circuit development such as radar, or in our actual or predicted achievements in miniaturizing electronic devices and making them reliable, it will be chastening to consider some biological data.

The bat, a creature of very limited intelligence but very ancient lineage, has perfected a system of navigation and target-location in the dark through a process of evolution over possibly 50 million years. Its supersonic echo-location system, which operates much as an underwater submarine-locating sonar system does, has an efficiency index, according to Dr. D. R. Griffin's computation, one billion times greater than man-made sonar[44]. Using only 10 micro-watts output at frequencies between 10 and 150 kilocycles, and with an auditory system weighing a fraction of a gram, the bat can not only avoid obstacles as small as wire of ⅕ millimeter diameter, but it can locate tiny insect prey in flight. It automatically adjusts, with distance from the target, the variable pulse rate and length of its frequency-modulated sonic emissions for optimum effectiveness, and some bats even have provisions for beam scanning. These remarkable little interceptors are also self-fueling and provide self-maintenance.

The bat first became of military value during the Civil War in the US when a regiment of soldiers guarded a cave in Texas which provided a source for nitre, required for gun-powder, in the bat guano deposits. During World War II, the assured success of the atomic bomb caused the fantastic secret "Project X-Ray"[45] to be dropped after two million dollars had been spent. It was proposed to parachute from an aircraft, over a city being bombed, a crate containing hundreds of refrigerated bats, each bearing a one-ounce time bomb capable of producing an eight-minute incendiary flame. Tests proved convincingly effective, when a New Mexico village and an auxiliary air-base became unintended targets. It is doubtful whether the sponsors of this unique bat-bomber squadron idea knew that their animated bombs had highly-refined radar homing mechanisms of high reliability that were not being utilized.

As a navigating servo-mechanism, man is not only surpassed by the bat, but even man's radar devices are exceeding in adaptability by the bat's automatic adjustments to target proximity which indicates reaction times far faster than man's.

Another example of our failure to yet equal nature's creation is in the communications mechanism of moths. This has usually been attributed solely to a sense of smell, but a recent account[46] claims an additional mechanism using infra-red radiation (proven not to be smell-detection by the moth's homing down-wind). In this case, the "hot mama" moth has a temperature only 11°F above the ambient temperature, but the male moths can home to her from a distance of seven miles on a wavelength of 7.7 to 13.3 microns, which is a so-called "atmospheric window" where the attenuation due to the air is low. The sensitive infra-red receptor antennae of the male moth, which are much more feathered than on the female and weigh less than a grain (1/30 ounce approx.), surpass the bat's mechanism in miniaturization and, as Scheer observes in his provocative paper, "We have much to learn from the birds and the bees"[46]. The study of these remarkable creatures might lead us to further much needed design "break-throughs".

An appreciation of the low order of safety factors and margins used in past electronic designs may perhaps be gained by considering what the frailty of our human bodies would be, if safety factors of only 1.5 to 1, often used in military electronics equipment (considered to be liberally designed), had been incorporated in our body members. Instead of such shoddy design, our Creator has provided factors of 10 or 20 to 1 in excess strength actually exhibited in bones and also in the excess breathing rate and blood flow available compared with normal load requirements. Our own electronic "creations" have been badly under-designed for military use, following, until recent years, domestic radio design practices rather than those of the more conservative telephone industry. Robert Lusser, formerly Reliability Co-ordinator at Redstone Arsenal, used to contrast the 200 year dependable life of the slow but sturdily-built sea-turtle with the 2 day span of the weak gossamer-winged may-fly for which he observes: "Mating takes place only once and death supervenes soon afterwards. What a miserable life!"[10]

MAINTENANCE AND ECONOMIC FACTORS

As the complexity of equipment increases, not only the reliability but the maintainability as well tend to deteriorate as shown previously in Figure 8. The potential danger of exceeding maintenance capabilities is indicated in the following two examples: (a) For the F-100 aircraft, the USAF provides 50 hours of maintenance for each hour of operation; (b) for Thor, Jupiter, Atlas and Titan missile squadrons, it is estimated that 70 electronic technicians will be required — a level which is 10 times that for a F-80 jet aircraft squadron. Maintenance costs over the lifetime of military electronic equipment vary from 10 to 100 times the initial cost[9, 21]. For ground telecommunications, the yearly maintenance cost varies from 0.6 for the AN/FPS-6 Radar to 12 or more for the AN/GRC-27 Radio Set relative to the initial costs[22].

These data, or the example given in a previous paper[1], indicate that considerable extra development and manufacturing costs to ensure reliability and dependability will pay dividends in reduced maintenance cost. The largest part of the maintenance cost is for labour, varying from 19 to 45 times that for material[22], indicating that more use of throw-away modules at higher unit cost would be economically justified[23]. An RADC study of US and British military maintenance practices, acknowledges a greater appreciation of, and achievement in maintainability, for the British designs. The result is reflected in yearly maintenance costs equal to initial costs, instead of double as for the US designs[16].

The skill of maintenance staffs not only affects the operational equipment reliability but the consumption of spares. Improved maintenance methods have reduced spares consumption 6 to 1 in radar stations[8], and contractor's engineers require for replacements only 1/7 to 2/3 of the tubes used by military technicians in maintaining airborne telecommunications equipment[47]. Total tube "replacement" rates (inclusive of "failures") in RCAF airborne equipment have been reduced and now amount to about 55% of total replacements. The ratio in both RCAF and USAF fixed ground equipment is currently 80% to 85%. It is believed that known improvements in maintenance methods and in design provisions could reduce this substantially.

Well-designed equipment is human-engineered for simplified operation and maintenance, but the great complexity of missile and ground electronic support systems is demanding the use of automatic testing equipment. Typical of this trend is the automatic test equipment for the AN/FSQ-7 Computer in the SAGE system in which the programmed tests are controlled by punched cards and magnetic tape. The availability goal of 99.943% (allowing only 20 interruptions per year averaging 15 minutes each) has been predicated not only upon use of reliable parts, and advanced equipment design including redundancy through use of duplexed units, but also on automated maintenance testing which is capable of detecting in advance 80% to 90% of incipient failures[48].

RELIABILITY AND MAINTAINABILITY OF MECHANICAL SYSTEMS

In aircraft and vehicular design engineering practice, use has been made of safety factors and safety margins based on a knowledge of product variability in performance under stress. Nevertheless, only during the past year have engineers begun to realize that the prediction and analysis techniques developed for electronic equipment can be applied advantageously to mechanical and electromechanical design problems. However, suitable modifications in techniques must be made to recognize the greater effects of wear-out, and the reduced — but not, however, negligible — applicability of assumptions regarding chance or haphazard failures exponentially related to time. For normal mechanical wear-out, the mean life occurs where there is a 50% survival, not 36.8% as for electronic devices, and the variance of the failure distribution around the mean time must be known also to evaluate the performance statistically for prediction use.

Those who are interested in considering the relationships of time, temperature, rotation, speed, bearing load etc, may consult the References given[49, 50], including the first Reliability Symposium paper which was presented this year by a Canadian, Mr. I. Kirkpatrick of RCA Victor Company Limited[51].

Estimates on one hour failure rates of the components of a hydraulic flight-control system[52] vary from a few parts per million for lines and fittings to 360 for actuating cylinders; and corresponding mean times to failure vary from 200,000 hours to 1,250 hours in US Navy fighter aircraft. Redundancy in control chains, power sources and components can effectively augment reliability.

Since 1958, several flight-control-system reliability design projects on which reports are available have been carried out by USAF's Wright Air Development Center, and a 97% FCS reliability requirement has been specified for the B-58 aircraft. Mean times to failure or reliability requirements have been specified for the B-58, B-70, F-106 and F-108 aircraft flight-control systems and flight and engine instruments.

The unfortunately well publicized history of failures of several missiles has attested to the fact that 60% to 80% of the failures have been due to mechanical causes[8]. In aircraft too, electronics shares the role of villain with mechanical and electro-mechanical devices. If the rate of progress in enhancing the reliability of electronic devices keeps up to the predictions made, mechanical devices will become the chief stumbling-block for aircraft and weapon systems. On the other hand, a very recent development shows promise of replacing complex electronic amplifiers for some purposes using a simple device employing a pneumatic-amplification principle.

SPECIFICATIONS AND CONTRACTUAL PROCEDURES

US military specifications on both reliability requirements and the conduct of reliability assurance programs have been available for some years covering electronic equipment and missile systems and, more recently, for aircraft systems and their flight-control systems. Several of these have been called up on RCAF contracts including MIL-R-19610(AER), MIL-R-25717C(USAF) and MIL-R-26484(USAF). The latter sets a minimum equipment operating life, with replacements of parts allowed, of 3000 hours and a mean time to failure of 500 hours. Detailed references to these specifications will not be made here except to note the large amount of attention given to providing guidance and reference information, and their reference to subsidiary specifications on human factors[21].

Also, belatedly, Specification MIL-M-26512(USAF) on "Maintainability Requirements for Weapon Systems and Sub-Systems", produced in 1959, is the first to treat maintainability quantitatively in terms of "availability", which involves rate of failure as well as total maintenance down-time. Unfortunately, definitions of "maintainability" are not uniform in various current specifications. MIL-M-26512 defines as "repairability" what the US Department of Defense AGREE Report[19] calls the "maintainability index", the inverse of the mean time to repair failures. The view of the US Navy, Bureau of Ships, and of other specialists, is concurred in that the maintainability index should be a measure of both preventive and corrective maintenance effort. MIL-R-26674 (USAF) covering "Reliability Requirements for Weapon Systems" is more of a design and production guide. Another recent specification of general interest covering the additional factor of "longevity", or the period between initial "debugging" and final wear-out, is MIL-R-26667A (USAF) on "Reliability and Longevity Requirements, Electronics Equipment, General Specification for". It is gratifying to find the illogical neglect of the complexity factor in other specifications corrected for in the recent MIL-R-26474(USAF) covering "Reliability Requirements for Production Ground Electronic Equipment", which sets a very moderate limit on failure rate determined by the number of tubes, transistors, and diodes, motors, relays and other miscellaneous component parts, applying for these individual factors that will have to be modified subsequently with advances in the state of the art.

The first USAF aircraft for which over-all flight-control system reliability requirements are known to have been prescribed are the B-58 and B-70. It is hoped that we can soon advance to the next obvious step of setting an "aircraft" systems factor, as has been done already for missile weapons. For the B-58 aircraft, a 3.5 million-dollar "Project Reliability" has been funded in the development stage by USAF. This considerable expenditure will produce a great saving, if it avoids the 50 million dollar after-production reliability fix required for the B-50 bomber, chiefly due to defects in its radar-bombing-navigation system. Mature initial design using effective reliability-maintainability engineering programs may delay production somewhat, but will hasten effective operational use. The need for reliability engineering in guided missiles is attested to by the need for 2300 post-prototype modifications in one of the earlier missiles[9].

Walton B. Bishop, of the USAF's ARDC Cambridge Research Center, has made an interesting, even if contentious, proposal for providing an incentive to contractors to augment reliability and maintainability[58]. The essential element in his philosophy is to contract the maintenance of equipment, as well as its supply, at a fixed price, so that the producer's profit incentive will depend upon his success in designing and manufacturing a dependable product. Conventional production to fixed-level performance requirements, at best, can only assure that a minimum level is attained.

An essential basis for formulating suitable reliability and maintainability specifications for equipment is that the operational users, with the assistance of their operational research staffs, formulate quantitative requirements in these areas for complete aircraft, weapon and their ground support systems. Progress has been evident in the missile field, and, for communication and radar equipment, a start, at least, has been made by providing the estimates from operational commanders recorded in the 1957 AGREE Report[19].

INDUSTRY AND MILITARY PROGRAMMES

Many papers are available describing how United States manufacturers have organized their reliability-maintainability control activities, and the writer's views on this have been expressed in a previous paper in 1958[18]. A digest of the basic steps in a complete programme, not

necessarily all in time sequence, is presented in the appendix. For both military and industrial organizations, a specialist engineering staff is necessary. The state of the art is expanding so rapidly that one specialist alone cannot even keep abreast of all phases. A programme involving about 5% of R & D costs and of engineering manhours appears to be a minimum effort, rising to 25% for some missiles. A somewhat lesser effort in the production phase is generally required. Suggestions on basic references, handbooks, guides to military practices etc, have been given in previous papers[1, 9]. In recent months, the Institute of Radio Engineers and American Society for Quality Control have set up a one week training course for intending specialists which is making a circuit of major US centers. Extension of this to Canada seems desirable. For its contribution, the RCAF Air Materiel Command sponsored lectures at several electronics manufacturers' plants in 1957.

The normal logistics support of military equipment in operational use involves modifications of parts that prove faulty in operation or unreliable, but use must be continued for some time of systems that are less reliable and maintainable than new designs with improved techniques, parts and more mature engineering would prove. The Royal Canadian Navy has had detailed reliability analyses of a sonar and a gun-fire control system carried out by an experienced contractor. The predicted performance of the parts and system generally agreed with the actual performance; and the stress-analysis techniques have disclosed where substantial gains in reliability can be made through circuit modifications, substitution of parts, and improved cooling.

This experience, substantiating US military experience reported in earlier papers[1, 3] indicates the benefit of making reliability-maintainability studies of existing equipment whose costly maintenance and unreliable performance can be improved greatly.

Canada is still lacking effort in the area of joint military-industry liaison and co-operation, whereas a great deal of the progress in reliability-maintainability engineering in the US has been due to such co-operative effort. Our progress could be accelerated by a similar joint acceptance of the challenge presented to Industry in 1957 by Major General Foulkes[2].

The opinions expressed in this paper are my own and do not necessarily represent those of the Department of National Defence. All data quoted are from unclassified sources including several not referenced.

APPENDIX

RECOMMENDED PROCEDURES IN RELIABILITY-MAINTAINABILITY CONTROL PROGRAMMES

Educational Programmes should be set up for management, engineering, production and quality control staffs based on adequate management policies (for details see Reference 1).

Organization responsible for reliability-maintainability control should be established with engineering, production, purchasing and quality control groups participating through a common co-ordinating agency[1, 18].

Design Factors for applicable operating and maintenance requirements should be established, and related human factors evaluated, by actual observation if possible.

Simplification in development of circuitry seeking reduction in complexity should be sought, after verifying that specified military characteristics are basic and without superfluities.

Failure Data for parts should be determined, and the relation established between operating electrical conditions and environmental factors and the predictable variations in the reliability of parts and assemblies.

Testing Programme should be planned and started early in project commencing with parts and later assemblies. Include tests to destruction to determine the variability under applicable stress conditions and to permit use of statistically-valid safety-margin concepts[1, 20] in place of obsolete safety-factor guesses. Thorough final prototype proving tests before production and comparisons of failures on test with predictions are essential.

Vendor Rating system should be set up and a programme of assistance to part suppliers established at start of project.

Prediction of reliability of parts, assemblies and whole system based on preliminary assumptions, and revised periodically, should be made, allowing for state-of-the-art factors and taking corrective action where critical complexity appears to be exceeded with respect to requirements.

Part Improvement programme should provide for substitution of more reliable parts including solid-state and magnetic devices.

Redundancy should be considered where critical complexity is exceeded using parts of insufficient reliability or stability. Use at unit, or assembly, rather than at system-level.

Automation in assembly, if feasible, will tend to reduce human errors and requires design consideration.

Design Reviews should be carried out periodically; initially to avoid misapplication of parts and to assure that safety margins meet needs.

Environmental protection or isolation of parts must be assured using sealing, pressurization, potting, printed circuits, shock and vibration damping etc where parts themselves are inadequate or extra safety factors are required.

Thermal Design based on competent engineering is an important tool in minimizing failures.

Monitoring provisions for performance checking should be provided in design — of the marginal checking type, where applicable — and simplified fault-locating facilities for maintenance.

Human Engineering should be applied in the mechanical design to promote ease of operation and maintenance in the man-equipment-environment system.

Accessibility is essential to minimized maintenance and should be suited to the applicable maintenance policy, for example, relative to suitability of expendable or repairable modules.

Instruction Manuals should be prepared applying human engineering considerations to suit the knowledge and skill levels of military technician and the physical and psychological conditions of tactical employment.

Performance Proving should be carried out by field tests before production, proving reliability and maintainability as well as other performance requirements. Necessary design revisions and corrective R-M predictions should follow.

Quality Control Programme should be integrated with reliability control in design and with failure-reporting in both production and field usage[18].

REFERENCES

(1) Soucy, C. I. – *Reliability Control of Electronic Equipment in Aircraft and Weapon Systems: Its General Management Aspects*, Canadian Aeronautical Journal, p 221-231, September, 1957.

(2) Foulkes, Maj. Gen. C. – *New Challenge – Even Higher Reliability*, Canadian Electronics Engineering, p 37, October, 1957, (Message to I.R.E. Canadian Convention at Toronto).

(3) Soucy, C. I. – *A Broad Survey of the Military Electronic Equipment Reliability Problem and Its Controlling Factors*, Proc. Electronics Components Symposium, p 8-23, Washington, D.C., 1956.

(4) Noble, H. V., and Larson, R. D. – *USAF Investigates Basic Moletronics*, Aviation Week, p 77, August 17, 1959.

(5) *Boom Year Seen for Electronics*, Missiles & Rockets, p 38-43, February 29, 1960.

(6) Lewis, Col. C. H. – *The Trend of Things to Come*, Institute of Radio Engineers Trans. on Component Parts, Vol. CP-6 No. 3, p 144-149, September, 1959.

(7) Roberson, Dr. R. E. – *Reliability in Space*, Electronic Equipment Engineering, p 21, May, 1958.

(8) Martinez, K. – *Looking Forward Into the Future*, Proc. 1956 Electronic Components Symposium, p 28-32, Washington, D.C., May 1-3, 1956.

(9) Soucy, C. I. – *The PROJECT MATURE Concept of the Design and Production Requirements for Requirements for Reliable and Maintainable Military Electronics Equipment*, Proc. Canadian Institute of Radio Engineers Convention, p 57-65, Toronto, October 6, 1958.

(10) Lusser, R. – *The Notorious Unreliability of Complex Equipments: A Condensed Presentation for Management Use*, Redstone Arsenal, Huntsville, Alabama, September, 1956.

(11) Holahan, J. – *How USAF Expects to Get Reliable Airborne Electronics*, Space Aeronautics, March, 1960.

(12) Wuerffel, H. L., and Troxel, D. J. – *Design Reliability Analysis – A Proven Technique for Product Control and Advancement*, Proc. Sixth National Symposium on Reliability and Quality Control in Electronics, p 377-387, Washington, D.C., January 11-13, 1960.

(13) Mariott, C. M. – *The Challenge of Space*, Electronics Industries, p 102-120, April, 1960.

(14) Dummer, G. W. A. – *Miniaturization and Micro-Miniaturization*, Wireless World, p 545-549, December, 1959.

(15) Child, T. M. – *Electronic Parts Reliability Requirements and Concepts*, Proc. 4th National Symposium on Reliability and Quality Control in Electronics, p 30-33, Washington, D.C., January 6-8, 1958.

(16) Ratynski, M. V. – *British and American Maintenance Techniques from the Maintainability Design Viewpoint*, Report RADC-TR-57-147, October, 1957, Rome Air Development Command, USAF.

(17) Colby, Brig. Gen. J. M. – *Operational Army Missiles*, Missiles & Rockets, p 9, December 1, 1958.

(18) Soucy, C. I., and Keefe, H. H. – *A Reliability Factor Model and Its Implications re the Relations Between Reliability-Maintainability Control and Quality Control*, Proc. RADC Military Electronics Reliability and Maintainability Symposium, p II-35-39, Griffith Air Force Base, Rome, N.Y., November 6, 1958.

(19) *Reliability of Military Electronic Equipment*, Report by the Advisory Group on Reliability of Electronic Equipment, Supt. Documents, US Government Printing Office, Washington, D.C., June 4, 1957.

(20) *Military Standard: Reliability of Electronic Equipment*, MIL-STD-441, US Government Printing Office, June 20, 1958.

(21) Schriever, F. M. – *Reliability Concepts are Measurable in Dollars*, Military Electronics, p 16-18, August, 1958.

(22) McLaughlin, R. L., and Voegtlen, H. D. – *Ground Electronic Equipment Support Costs re Reliability and Maintainability*, Proc. 5th National Symposium on Reliability and Quality Control in Electronics, p 36-42, Philadelphia, Pa., January 12-14, 1959.

(23) Andrea, J. J., and Ratynski, M. V. – *A Study and Design Evaluation of the Disposal at Failure Maintenance Concept*, Trans. Institute of Radio Engineers National Convention, p 251-262, New York, March 15, 1959.

(24) Pieruschka, E. – *Optimum Allocation of Funds for Reliability of Guided Missiles*, Reliability Coordination Office, Redstone Arsenal, Huntsville, Alabama, January, 1955.

(25) *Workmanship and Design Practices for Electronic Equipment*, Bureau of Ordnance, United States Navy, Publication OP-2230, 1st Rev., April 22, 1959.

(26) Klass, P. J. – *Moletronic Developments Demonstrated*, Aviation Week, p 79, 81, February 8, 1960.

(27) Nucci, E. J. – *Progress Report on Ad Hoc Study on Parts Specifications Management for Reliability*, Inst. Radio Engineers Trans. on Component Parts, Vol. CP-6, No. 3, p 128-143, September, 1959.

(28) Sobel, M., and Tischendorf, S. A. – *Acceptance Sampling with New Life Test Objectives*, Proc. Fifth National Symposium on Reliability and Quality Control in Electronics, p 108-118, January 12-14, 1959.

(29) Lusser, R. – *Reliability Through Safety Margins*, Redstone Arsenal, Huntsville, Alabama, October, 1958.

(30) Wooley, M. C. – *Components for Submarine Telephone Cable Repeaters*, Institute of Radio Engineers Trans. on Component Parts, Vol. CP-6, No. 1, p 34-41, March, 1959.

(31) Jacobs, R. M., and Rogers, B. F. – *Designing for Maintainability*, Proc. Electronic Industries Assoc. Conference on Maintainability of Electronic Equipment, p 23-35, May 27-28, 1958.

(32) Wulfsberg, A. H. – *Integrated Electronic Systems Using the Modular Design Concept*, Proc. Second National IRE Conference on Military Electronics, p 359-366, Washington, June 16-18, 1958.

(33) Stone, R. O. – *Some Aspects of Disposal-At-Failure Maintenance of Military Airborne Electronic Equipment*, Proc. Fourth Signal Maintenance Symposium, p 8-1 to 8-13, USASC, Fort Monmouth, May, 1960.

(34) *Reliability Stress Analysis for Electronic Equipment*, Iss. 2, Radio Corporation of America, Defense Electronic Products, Camden, N.J., Report TR-59-416-1, January 15, 1959.

(35) Thomas, J. W. – *Predicting Electronic Equipment Maintainability*, Proc. 5th National Symposium on Reliability and Quality Contrrol in Electronics, p 265-269, January 12-14, 1959.

(36) Thomas, H. E., Soukup, J., and Brobst, W. — *Maintainability Profile Analysis*, Institute of Radio Engineers National Convention, New York, March 21-24, 1960.

(37) Klass, P. J. — *Video Sonics Cuts Production Defects*, Aviation Week, p 75, 76, 78, 81, January 4, 1960.

(38) Chase, W. P. — *Man-Machine Balance Holds Key to System Reliability*, Aviation Age, p 72-76, May, 1958.

(39) Fleckinger, Maj. Gen. D. G. — *Man's Flexibility Held Asset in Space Flight*, Aviation Week, p 55-56, February 17, 1958.

(40) Hauty, G. T. — *Maximum-Effort-Minimum-Support Simulated Space Flights*, Aero-Space Engineering, p 44-47, April, 1960.

(41) Birmingham, H. P. — *A Design Philosophy for Man-Machine Control Systems*, Proc. Institute of Radio Engineers, p 1748-1758, December, 1954, and May, 1955, p 623.

(42) Miller, G. A. — *The Human Link in Communication Systems*, Proc. National Electronics Conference, p 395-400, October 1-3, 1956.

(43) Peale, M. I. — *Try This One on Computer Designers*, Electronic Design, p 51, March 16, 1960.

(44) Griffin, D. R. — *More About Bat Radar*, Scientific American, p 40-44, July, 1959.

(45) Drimmer, F. (Ed.) — *The Animal Kingdom*, Vol. I, Mammals, p 133-135, Greystone Press, N.Y., 1954.

(46) Scheer, Geo. H. — *Some New Horizons in Communication*, Proc. National Aero-Electronics Conference, p 102-106, Dayton, Ohio, May 13-15, 1957.

(47) *Yearly Progress Report 1956*, ARINC Research Corp., Washington, D.C., April 1, 1956.

(48) *AN/FSQ-7 Combat Control — Introduction to Philosophy of Maintenance*, USAF Manual T.O. 31 P2-2 FSQ-7-132, November 15, 1956.

(49) *Techniques of System Reliability Measurements*, ARINC Research Corp. Pub. No. 101-6-129, Vol. 1, December, 1959.

(50) Koff, R. M. — *What the Experts Tell Us About Mechanical Reliability*, Production Engineering, p 27-30, November 16, 1959.

(51) Kirkpatrick, I. — *Predicting the Reliability of Electromechanical Devices*, Proc. 6th National Symposium on Reliability and Quality Control in Electronics, p 272-281, Washington, D.C., January 11-13, 1960.

(52) Knight, C. R. — *More Reliable Hydraulics in Flight*, Control Engineering, p 125-127, October, 1959.

(53) Bishop, W. B. — *Reliability and Maintainability Assurance*, Air Force Cambridge Research Center, ARDC, Bedford, Mass., Report FCRC-TN-58-569, ASTIA Document No. AD-160882, November, 1958.

ANNUAL GENERAL MEETING

The Annual General Meeting of the Institute will be held at

THE ROYAL YORK HOTEL, TORONTO

on the

25th and 26th May, 1961

The technical sessions will be grouped around a central theme, which is not easy to define but will be recognized from the headings of the sessions themselves; these are tentatively planned as follows:

Aerodynamics of VTOL/STOL and Helicopters
Ground effect vehicles
Small engines
Small, small aircraft (ultra-light, etc)
Man-powered flight

Members of the C.A.I. are invited to present papers on any of the above-mentioned subjects and anyone wishing to do so should submit a brief summary for consideration by the National Programmes Committee. Such summaries must be in the hands of the Secretary by the 31st December, 1960.

METHODS OF MEASUREMENT OF AIRCRAFT DYNAMIC STABILITY DERIVATIVES†

by K. J. Orlik-Rückemann*

National Aeronautical Establishment

SUMMARY

The numerous methods available for determination of dynamic stability derivatives of aircraft are presented and grouped according to a convenient classification system. Both free flight and wind tunnel methods are considered. The basic aspects of each method are described in the text and illustrated by a schematic drawing.

INTRODUCTION

Stability characteristics of an aircraft can be obtained from an analysis of its equations of motion. These consist of three equations describing the motion of the aircraft centre of gravity and three describing the motion of the aircraft around its centre of gravity. The equations of motion consist of mass or inertia terms, gravity terms, thrust terms and, finally, aerodynamic terms. These latter terms are partly associated with the equilibrium conditions of straight flight (that is involving only angle of attack and angle of sideslip), and are then called static or stationary terms, and partly with the equilibrium conditions of curved or rolling flight or with the unsteady flight conditions (that is involving angular velocities or linear and angular accelerations), and are then often referred to as dynamic or unsteady terms.

The deduction and discussion of an aircraft's equations of motion have been presented in great detail in many standard reference books and will not be dealt with here. It will only be recalled that a system of these equations consists normally of three force and three moment equations, and that it is a standard procedure to distinguish between the longitudinal stability equations, which describe the motion in the aircraft's longitudinal plane of symmetry, and lateral stability equations, which describe the motion outside that plane. It is often possible to consider each of these two groups of equations separately, if the effect of cross-coupling terms (aerodynamic or inertia) can be assumed to be small.

Aerodynamic forces and moments are usually represented in the equations of motion in the form of series expansions in variables of motion and their time derivatives. The coefficients in these expansions are referred to as stability derivatives. Thus, the dynamic stability derivatives are those coefficients which express the aircraft aerodynamic reactions caused by variation with time of aircraft variables of motion.

†Paper based on NAE Report LR-254.
*Head, High Speed Aerodynamics Laboratory

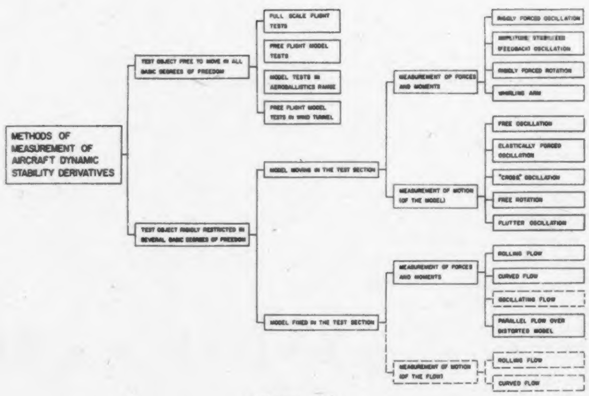


Figure 1
Methods of measurement of aircraft dynamic stability derivatives

Stability derivatives are often given in a dimensionless form. As in the case of many other aerodynamic data, they can be obtained from full scale tests as well as from experiments on scaled models. A list of the most common stability derivatives associated with motions of a rigid aircraft is given in the Appendix.

EXPERIMENTAL TECHNIQUES

There are many types of experimental techniques which are suitable for measurements of dynamic stability derivatives. In order to emphasize better their relative characteristics an attempt is made here to arrange them in a classification system, which is presented in Figure 1. The methods are first divided into two large groups, according to whether the test object is, or is not, free to move in all the basic degrees of freedom.

The expression "test object" in the first group may stand for an aircraft model or a full scale aircraft, whereas in the second group it refers, for obvious reasons, mostly to a scale model. It may appear strange that a full scale aircraft, which is already built and whose stability characteristics can be directly obtained from flight tests, should be used for measuring the stability derivatives. However, in view of the usually encountered uncertainty in a theoretical determination of many dynamic derivatives and the limitations of scale experiments, it is clear

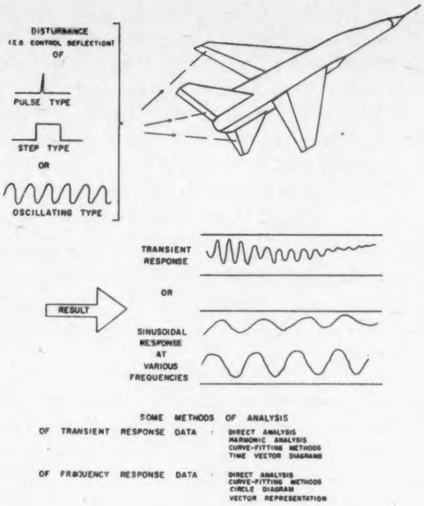


Figure 2

that full scale information can be extremely valuable in order to correlate the different results and thereby obtain a check on the methods used and on possible scale effects. Furthermore, if any change in the stability characteristics of the aircraft is desirable, the best way to identify it is to perform, on an analogue computer, an analysis of the appropriate equations of motion and determine what derivative or what combination of derivatives should be changed and by how much. From this the required changes in the aircraft configuration or in the artificial stability system of the aircraft may be deduced.

By "basic" degrees of freedom the usual three translational degrees of freedom of the aircraft centre of gravity and three rotational degrees of freedom around the aircraft centre of gravity are meant.

Test object free to move in all basic degrees of freedom

To this first group of experimental techniques belong:

(1) Full scale flight tests
(2) Free flight model tests
(3) Model tests in aeroballistics range
(4) Free flight model tests in wind tunnel

Full scale flight tests

Full scale flight tests (Figure 2), are usually conducted in such a way that the aircraft response to a control deflection is measured. Two types of responses can be distinguished; namely, transient response to a pulse-type or step-type control deflection or frequency response to a periodically oscillating control. Transient response data can be transferred to the frequency plane and vice versa by mathematical means, but the accuracy of this procedure may sometimes be inadequate, depending on the characteristics of the initial input. From the subsequent analysis of aircraft response most of the stability derivatives can be obtained. Longitudinal and lateral derivatives are usually measured in separate flight tests, and the detailed procedure in evaluation of the derivatives may be somewhat different in the two cases. However some common methods of analysis can be distinguished, for instance:

(a) direct analysis of transient response data in one degree of freedom;

(b) harmonic analysis of transient response data by Fourier transformation and determination of transfer functions from frequency response curves;

(c) curve-fitting methods, in which transient or frequency responses are compared (using templates and/or analogue computers) with predicted responses, calculated from assumed equations of motion; the least-squares method is applied to the data obtained to determine the coefficients in integral expressions of the transfer functions (matrix methods) or coefficients in the expressions of the time histories of the input and output functions (exponential approximation);

(d) time vector method of analysis, in which derivatives are obtained from the requirement that for each degree of freedom the vector polygon of pertinent force or moment components must close;

(e) direct analysis of frequency response data; determination of transfer functions;

(f) circle diagram method of analysis of frequency response data;

(g) vector representation of frequency response data and application of the least-squares method to the data in the resulting real and imaginary equations to determine their coefficients and finally stability derivatives.

Whenever the above methods result in expressions for transfer functions, equations of motion or corresponding time histories, stability derivatives or their combinations can be obtained from the coefficients in these expressions. In this connection, it is often convenient to neglect some of the less important derivatives (such as, for instance, C_{Yr} or C_{Yp}) or to assume values of those which are more easily determined by more direct methods (such as is often the case with C_{lp} and some static derivatives) and solve the thereby reduced system of equations for the remaining derivatives.

Free flight model tests

The free flight model tests (Figure 3), are carried out by launching models by means of an integral rocket

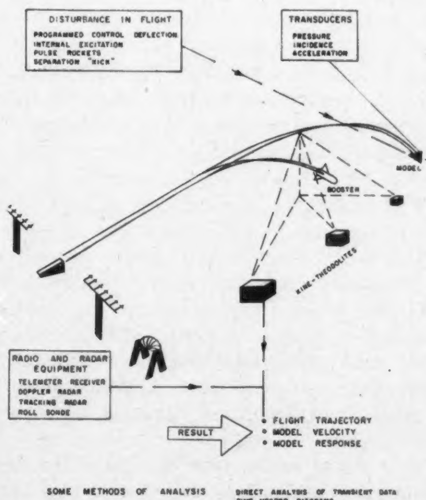


Figure 3

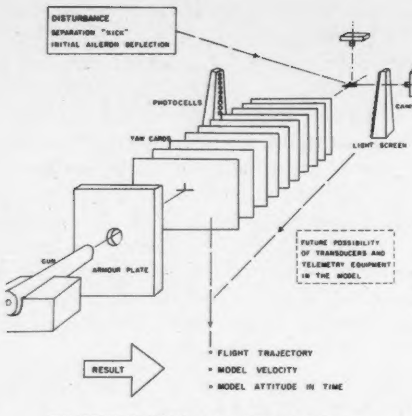


Figure 4
Model tests in aeroballistics range

motor or using a separating rocket booster to which the model is initially attached. In the case of tests for the determination of the dynamic stability derivatives, the booster method is usually considered more advantageous, as it allows a freer choice of the centre of gravity position and mass-distribution of the model, and is well suited to installation of devices needed to introduce disturbances in flight, such as programmed control deflection, internal excitation or pulse rocket charges. The response of the model is measured by suitably distributed incidence and acceleration (linear and angular) transducers and telemetered to a ground receiver, together with data on control position and information on static and total pressure. The trajectory of flight is obtained from integration of the accelerometer data, from a tracking radar set or from a system of kine-theodolites; the velocity of the model is determined from the pressure data or is measured by a Doppler velocimeter radar; and the velocity in roll is obtained from a roll sonde receiving plane-polarized radio signals from the telemeter antenna. Atmospheric conditions are recorded by means of radio sondes released immediately before or after model flight. From this information and from an assumed system of equations of motion, many stability derivatives or their combinations can be obtained. The analysis is usually carried out directly from transient response data or by means of time vector diagrams. A digital method, applying the least-squares method to a great number of data points and solving (on a digital computer) the system of equations of motion for the derivatives, is sometimes also used. As in the case of full scale flight tests, the longitudinal and lateral degrees of freedom are usually considered separately; that is, models instrumented for recording the longitudinal responses are subjected to longitudinal disturbances and only symmetrical equations of motion need to be used for the analysis of results. The same applies to lateral motions, which, however, are always more complicated to analyze because of the coupling between roll and yaw.

The free flight model tests are also used for direct measurement of the damping-in-roll derivative, C_{l_p}. Two techniques are used for this purpose; firstly, one in which the model is subjected to a known torque in roll, e.g. from an internal rocket nozzle, and the resulting increment in rolling velocity is measured, and, secondly, one in which the entire test vehicle is forced to roll by off-set stabilizing fins or other means, and the resulting damping moment is measured on a balance between the model and the test vehicle. Both these methods actually belong to the second group of testing techniques, because the model is restricted in all degrees of freedom except roll.

To the free flight model tests also belongs the technique of free falling models, employing unpowered, air-launched test vehicles. This technique, however, is often considered less convenient and less flexible, and its use is rather limited.

Model tests in aeroballistics range

In an aeroballistics range (Figure 4), the model, enclosed in a sabot carrier, is launched horizontally from a smooth-bored gun. The sabot disintegrates immediately after leaving the muzzle and is arrested by an armour plate in the entrance to the range. The model enters the range and passes through a large number of vertical paper cards or spark photographic stations (which take simultaneous records in two directions perpendicular to the direction of flight), from which trajectory data and data on the angular position of the model are obtained. Longitudinal time history of model flight is determined with the help of numerous light screens and electronic chronographs.

Several methods of analysis can be used, most of them applied directly to transient response data. Thus the techniques of curve fitting (on an analogue computer) and of time vector diagrams are used, as well as direct analysis of time history records in cases where model motion involves mainly one or two degrees of freedom. Also an analysis of transient data using equations of motion in vector form and an assumed form of transient solutions is sometimes used. The techniques of testing in aeroballistics ranges are now being developed towards using acceleration and pressure transducers in the model and telemetering model data in the same fashion as in the

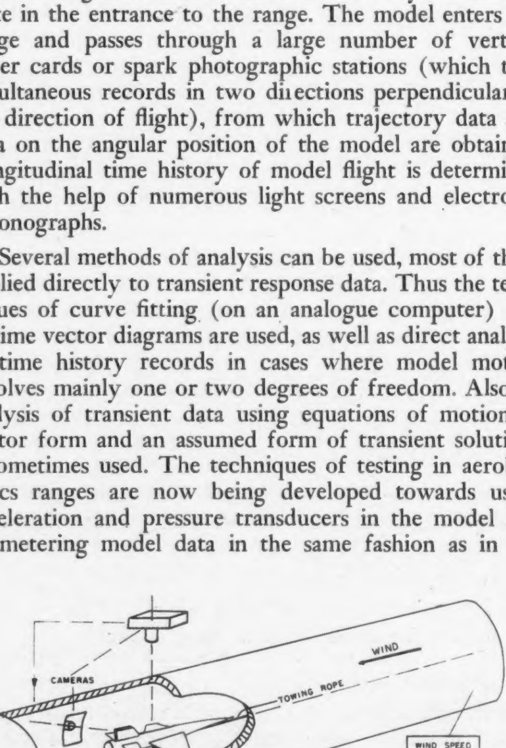


Figure 5
Free flight model tests in wind tunnel

free flight model tests. This will eventually simplify the methods of data collecting and increase the accuracy of the analysis.

Free flight model tests in wind tunnel

In a so-called "free flight" wind tunnel (Figure 5), the model is flown by two or three operators (pilots) who can regulate wind speed and vertical slope of the tunnel axis, thrust of the model engine and position of the model controls. Once the wind speed, tunnel slope and model thrust are so set that equilibrium is reached, the model controls are displaced and the responses of the model in three mutually perpendicular planes can be recorded by three movie cameras. A variant of this method involves using a towing rope instead of thrust-producing devices in the model. Tests of this type are usually carried out to study flight behaviour of a model, but in principle also stability derivatives can be determined by methods such as those used in the aeroballistics range tests.

Another case where a model performs free flight in a wind tunnel is the case of a model which is gun-launched at high speed upstream through the test section of a supersonic wind tunnel. Hypersonic model speeds are attained in this way. Again, analysis of the same type as used in the aeroballistics range tests, for instance by a curve-fitting method, can be applied. The method has been used to obtain damping-in-roll derivative.

Still another type of experiment has been recently suggested in which a model is suspended on a thin wire in the working section of a hypersonic shock tunnel. When the tunnel starts the wire breaks off, and the free flight of the model is photographed with a high speed framing camera. The whole process takes only a few milliseconds. Evaluation of straight damping derivatives from such experiments seems to be possible, even if it has not yet been attempted.

In the four test techniques mentioned above, the model was essentially free to move in all six degrees of freedom. Some minor disturbances on model motion were imposed by the techniques used, e.g. by paper cards in the case of the aeroballistics range or by remote control cables in the case of the "free flight" tunnel, but these could be considered as minor irregularities (to be corrected for) rather than real restrictions of freedom of motion. Thus usually a complete group of equations of motion (longitudinal or lateral) had to be considered during the analysis of test results.

Test object rigidly restricted in several basic degrees of freedom

The second large group of experimental techniques, suitable for measurements of dynamic stability derivatives, consists of techniques in which the model is rigidly restricted in several of the basic degrees of freedom. In fact, in most cases discussed below, the model is free to move in one degree of freedom only, thus involving only one equation of motion. The analysis of the test results is thus basically much simpler and therefore, in principle, more accurate. Of course, there are other factors which affect the accuracy of results, such as scale effects and wind tunnel and model support interference, so that the final accuracy of results has still to be judged individually from case to case.

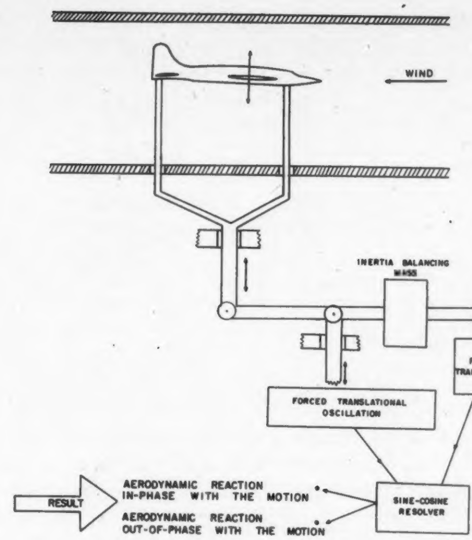


Figure 6

All techniques in this group are based on model tests in wind tunnels. In principle it would be possible to consider here also other forms of tests such as models attached to a high speed, rocket sled or models attached to an aircraft wing (wing flow technique), but these methods are in general not used for determining dynamic stability derivatives and, consequently, will not be discussed further. One exception has been noted before, that is, the free flight test vehicle for continuous roll used to determine C_{lp}.

The dynamic stability derivatives can be determined from wind tunnel tests using models which describe a rotational or oscillatory motion in relation to a parallel air stream. This relative motion occurs when models rotate or oscillate in a test section with parallel air flow, but can also occur when the flow is curved, rotates or oscillates in a test section in which the model is rigidly fixed. Also, the measurements can be carried out according to two main principles; namely, by measuring forces and moments (or pressures) when the relative motion between model and air stream is given, or by measuring the relative motion when forcing or restraining moments and forces are given.

Thus methods in the second group can be divided as follows:

(1) Model moving in the test section
  (i) Measurement of forces and moments
  (ii) Measurement of motion (of the model)
(2) Model fixed in the test section
  (i) Measurement of forces and moments
  (ii) Measurement of motion (of the flow)

Each of these groups consists in turn of several methods, as can be seen from Figure 1. The individual methods will now be briefly described.

Model moving in the test section

Measurement of forces and moments

The method of *rigidly forced oscillation* (Figure 6) can, in principle, be used to determine all the derivatives,

except those due to rotational roll. A preselected motion is imparted to the model, and forces and moments between the model and the forcing part of the rig are measured. The model motion can be angular or translational and is most often harmonic, in which case the derivatives are obtained from the in-phase and out-of-phase components of the measured aerodynamic reactions. To keep the ratio between the inertial reactions (tare) and the measured aerodynamic reactions small, it is usually required to balance out (by additional masses or springs) the inertial reactions. This often introduces a considerable amount of experimental difficulty, especially at high frequencies. The model motion can also be chosen in such a way that the model performs a combination of angular and translational motions, maintaining all the time the same orientation in relation to the relative wind, which results in a kind of "snaking motion" from which the derivatives in pure pitching (e.g. C_{mq}) or in pure yawing (e.g. C_{lr}) can be determined. The technique of measuring the in-phase and out-of-phase components of a reaction can also be applied in one degree of freedom (e.g. vertical translation) while the motion is being imparted (not necessarily rigidly but in such a way that the motion is known and harmonic) to the model in another degree of freedom (e.g. pitching), resulting in data for determination of corresponding derivatives (e.g. $C_{Lq} + C_{L\dot{\alpha}}$).

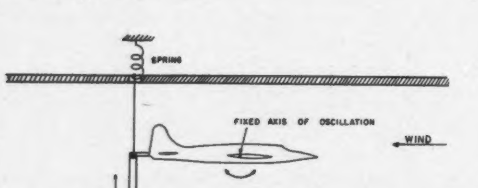


Figure 7

A method which can be successfully used for determining the oscillatory damping and stiffness derivatives is the one of *amplitude stabilized (feedback) oscillation* (Figure 7). The most usual arrangement consists of a feedback system connecting the displacement transducers on the model suspension with an electromagnetic oscillator and also including provisions for a 90° phase shift and amplitude stabilization. Derivatives such as $(C_{mq} + C_{m\dot{\alpha}})$, $(C_{nr} - C_{n\dot{\beta}})$ and C_{lp} are obtainable from measurements of the energy which is required to keep the oscillation at a constant amplitude, and aerodynamic stiffness derivatives such as $C_{m\alpha}$ and $C_{n\beta}$ are obtainable from frequency measurements. The method can be conveniently applied at both low and high speeds and in a large range of frequencies. The feedback system automatically takes care of setting the frequency at resonance, thus eliminating the need for manual tuning of frequency during the test, which is necessary when oscillation is excited by means of a separate oscillator.

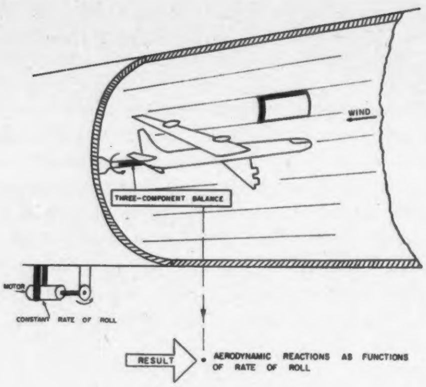


Figure 8

A convenient method for the determination of derivatives due to rolling (such as C_{lp}, C_{np}, C_{Yp}) is the method of *rigidly forced rotation* (Figure 8). The method is quite similar to that of rigidly forced oscillation, but it has the great advantage of avoiding difficulties with inertia effects. The model is forced to perform a known steady rolling motion by means of a hydraulic or an electric motor or a previously calibrated windmill arrangement. The roll response (damping-in-roll) can be measured between the driving motor and the model, or between the whole apparatus and the wind tunnel structure, which is often more convenient. The differences in results of tests with continuous rolling or with oscillation-in-roll, which are due to a different time history of the motion in the two cases, are often small. In cases where they are not small, as often happens in tests at high incidence, both types of motion are of interest, the continuous one in connection with rolling performance and the oscillating one in connection with stability analysis.

Here belongs also the free flight test method, in which the complete test vehicle is forced to roll continuously

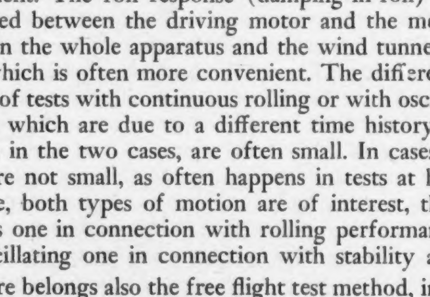


Figure 9

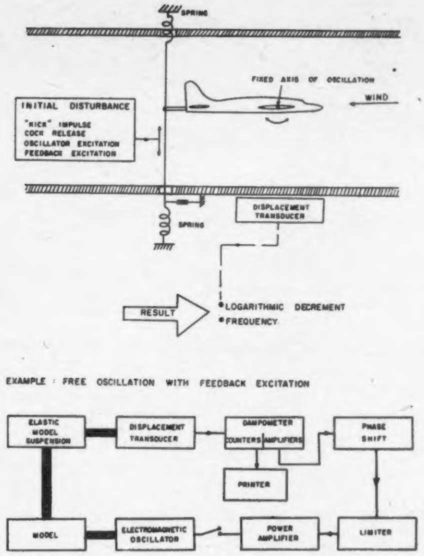


Figure 10

by off-set stabilizing fins, and the rolling moment is measured between the model and the rest of the test vehicle. As with other types of free flight tests, the rolling velocity is obtained from a spin sonde, the forward velocity from a Doppler velocimeter, and the measured rolling moment is telemetered back to a ground receiver.

The method of rigidly forced, continuous rotation is not limited to rolling motion but can also be used to obtain pure motions in yaw and pitch. In this case, however, the motion must take place for obvious reasons in a closed chamber with zero air speed, rather than in a wind tunnel. The difference is important enough to warrant a separate name for the method, namely that of *whirling arm* (Figure 9), on which the model is rotated. Forces and moments are measured between the model and the arm. Careful calibration is needed for effects of the centrifugal force. The principal disadvantages of the method are that after the first revolution the model passes through an already disturbed air and also that the air in the chamber gradually starts to co-rotate with the arm. This last effect is partially eliminated by using radial ribs along the peripheral walls and on the floor of the chamber to slow down the co-rotating air. Derivatives due to pure pitching (such as C_{mq}) and pure yawing (such as C_{nr}, C_{lr}) can be obtained. The method has been used only for low speed work.

Measurement of motion

The method of *free oscillation* (Figure 10) is probably the oldest and is usually considered to be the simplest and most straightforward for determination of the oscillatory damping derivatives, such as $(C_{mq} + C_{m\dot{\alpha}})$, and aerodynamic stiffness derivatives, such as $C_{m\alpha}$. It simply consists of the evaluation of decaying oscillations performed by an elastically constrained model following an initial disturbance. With modern instrumentation the accuracy of the determination of damping derivatives is often considered equal to or even higher than accuracy obtainable with any other method because of the straightforward type of analysis. The accuracy of frequency measurements obtainable is about the same as with other methods. The initial disturbance has usually the form of an abrupt release from a deflected position, but at higher frequencies it can be conveniently replaced by a sudden cut-off from an excited oscillation of a desired amplitude, sometimes in connection with a feedback system to secure automatically the frequency setting at resonance. It lies in the nature of the method that the results are representative of an amplitude range rather than of a discrete value of amplitude, but with modern instrumentation this amplitude range can be made very small, so that results as functions of amplitude (of interest in the case of slight nonlinearities) can usually be obtained as conveniently as with constant amplitude methods.

In the method of *elastically forced oscillation* (Figure 11) a harmonic motion is imparted to the model through a linear spring. The oscillatory damping derivatives can be determined from the amplitude ratio at resonance between the forcing and the forced motions and the value of the resonance frequency. Alternatively, with another method of analysis, the same result can be obtained from measurement of the ratio of forced amplitude at two close values of frequency, one of them being frequency at resonance. Still another method, which can be applied if the resonance condition is difficult to maintain, requires measurement of the amplitude ratio between the forcing and the forced motion at any frequency, the value of this frequency and, in addition, the phase angle between the forcing and the forced motion.

If a harmonic motion is imparted to a model in one degree of freedom and the *model response in a second degree of freedom* (Figure 12) is measured, the appropriate cross derivative can be determined. A particularly

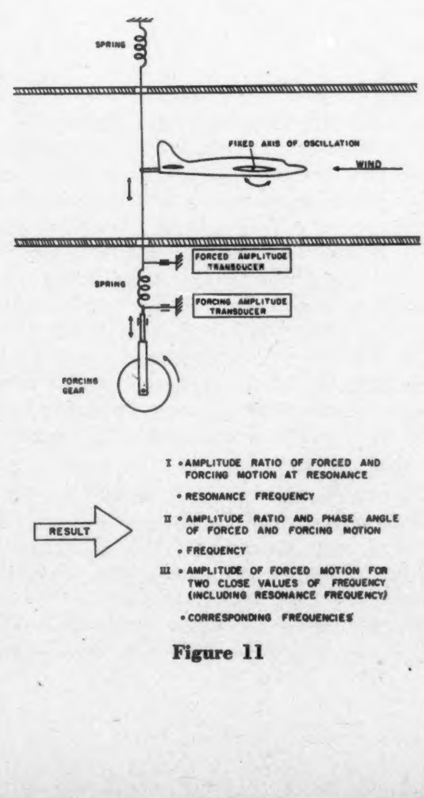


Figure 11

simple analysis can be used, if the frequency of the forcing motion is adjusted in such a way that the forcing and forced motions are in phase. The desired cross derivative (say C_{n_p}) is then simply equal to the amplitude ratio between the forced and the forcing motion multiplied by the oscillatory damping derivative for the forced motion (in that case $C_{n_r} - C_{n_{\dot\beta}}$), which has to be determined from separate tests. If an accurate adjustment of forcing frequency is difficult to carry out, a more general method can be applied, in which measurement of the amplitude ratio and the phase angle of the forcing and forced motions as well as a determination of frequency are required. This method resembles in a way the method of elastically forced oscillation, although the forcing and the forced motions occur in different degrees of freedom of the model.

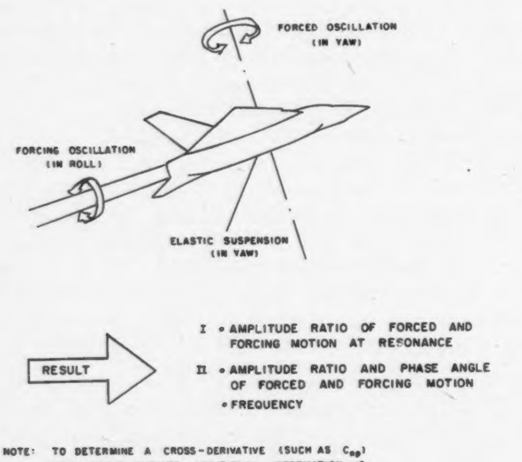


Figure 12
"Cross" oscillation

A special method which can be used only for the determination of the damping-in-roll derivative C_{l_p} is the method of *free rotation* (Figure 13). There are two variants of this method; firstly, one in which an initial rolling velocity is imparted to a model and the subsequent decay of the rolling velocity is measured, and secondly, one in which the rotation is forced continuously by a known torque and the resulting rolling velocity is measured. The known torque can be obtained by an aileron or fin deflection on the model itself or by a specially added forcing vane, and can be calibrated before the test. In the case of free flight model tests the known torque is sometimes produced non-aerodynamically, e.g. by means of a rocket motor with a "canted nozzle" assembly.

With a model suspended in such a way that *flutter oscillation* (Figure 14) in one or several degrees of freedom can occur, the aerodynamic stability derivatives can be obtained from measurements of the flutter characteristics, that is wind speed and frequency at fully developed flutter conditions. By repeating this procedure for a few values of stiffness or inertia, enough data can

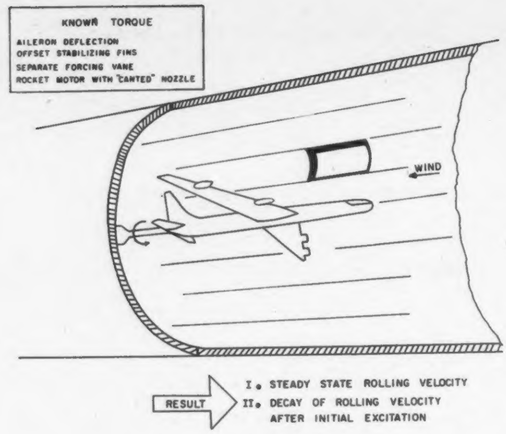


Figure 13

be obtained to permit solving the aerodynamic derivatives from the flutter equation(s) of the oscillating system.

Model fixed in the test section

In the few methods mentioned below, the model is fixed in the test section, with the advantage of enabling all measurements to be made on static balances of usual type.

In a test section with *rolling flow* (Figure 15), derivatives due to rolling (such as C_{l_p}, C_{n_p}, C_{Y_p}) can be measured. The air stream is rotated by means of a variable speed rotor using blades with radially increasing chord. The test conditions are somewhat different from the conditions when rolling an aircraft (or model), because of the presence of a radial pressure gradient in the air due to the centrifugal force. If the flow could be considered a potential flow and the model were symmetrical (and symmetrically mounted), the total effect of such a gradient would be zero, but in cases of incidence or yaw, and in the inevitable presence of model boundary layer, a correction has to be applied to account for this effect.

Similar test conditions exist in a test section with *curved flow* (Figure 16), where the derivatives due to

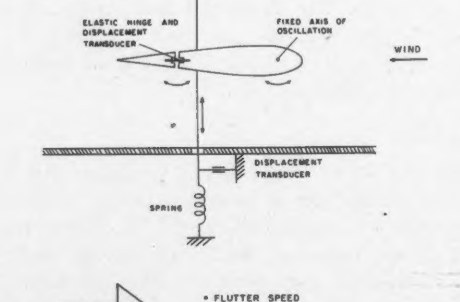


Figure 14

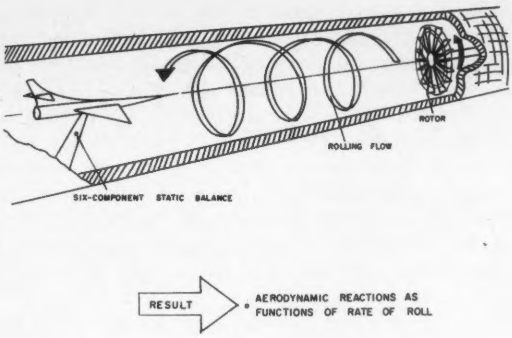


Figure 15

pure yawing (such as C_{nr}, C_{lr}, C_{Yr}) and pure pitching (such as C_{mq}, C_{Lq}) can be measured. The air stream is curved by means of flexible side walls and the desired velocity variation (proportional to the local radius of stream curvature) is produced by upstream drag screens with density decreasing outwards. Test sections with rolling or curved flows are used only for low speed work.

It is in principle possible to visualize a test section with *oscillating flow*, which could be generated, for example, by a longitudinally oscillating bump on the wind tunnel wall or by a set of oscillating vanes upstream of the model ("venetian blind" arrangement). Such an apparatus would permit measurements of the oscillatory derivatives on models fixed in the test section. So far no such technique has been used for the determination of derivatives, and serious difficulties in connection with establishment of correct form of such an oscillating flow can be anticipated.

Instead of placing a model in a curved or rotating flow it is also possible to use a *parallel flow over a model distorted* (Figure 17) in such a way that pressures at different stations on the model are similar to what they would have been on an undistorted model in a curved or rotating flow or on a rolling or yawing model in parallel flow. For instance, a stationary wing model with linearly distributed, asymmetrical twist gives approximately the same pressure distribution over the wing as the pressure distribution over a wing performing a rolling motion. The method has the advantage of measuring dynamic derivatives on stationary models using static

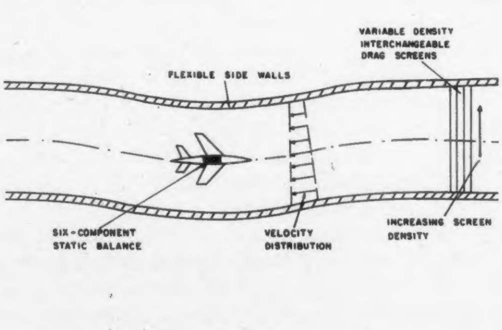


Figure 16

balances, but has the large disadvantage of involving several complicated and costly models.

It is theoretically possible to reverse the procedure in the case in which the dynamic derivatives are determined from the motion of models disturbed by the flow, and instead *determine the flow disturbed by stationary models* in the rotating or curved flow, or by rigidly moving (rotating or oscillating) models in a parallel flow. Such a measurement could be done, for instance, by a grid of pitot probes behind the model. The method seems hardly practical, but is included here merely as a curiosity.

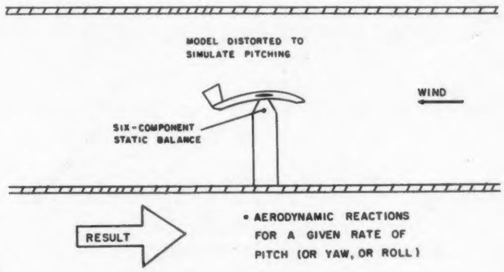


Figure 17

CONCLUSION

In principle the methods in group 1, in which the aircraft or the model is free to move in all degrees of freedom, can produce, with a sufficiently extensive test programme and with a very careful and detailed analysis, most of the dynamic derivatives associated with motion of the rigid aircraft. This procedure is not always accurate enough and often not at all practical, but in principle it is available because in the methods of group 1 the analysis is based on a more or less complete set of equations of motion in which most of the derivatives appear.

The methods in group 2, which are mainly wind tunnel methods, are much more limited in this respect, as usually only one or two degrees of freedom are considered in a given test. This, on the other hand, constitutes an important factor in establishing the high accuracy of analysis of such tests. The individual methods in this group are applicable only to measurement of particular groups of dynamic derivatives, such as all the damping derivatives associated with angular one degree of freedom oscillation or all derivatives associated with the steady state rolling.

A list of methods, which in principle are available for measurement of a given dynamic derivative, is given in Figure 18. As can be seen, in some cases two or even three methods, even though completely different from the point of view of techniques used, can be grouped together as possible for the determination of a given derivative or group of derivatives.

The derivatives can also be grouped together, according to the common methods required for their determination. The 21 dynamic derivatives or combinations of derivatives considered here can thus be gathered in six groups. It is important to note that oscillatory and rotational derivatives are considered here separately, as different methods are required for their measurement even though their actual values in some cases may be

METHOD \ DYNAMIC DERIVATIVE		$C_{lp,osc}$ $C_{mq}+C_{m\dot{\alpha}}$ $C_{nr}-C_{n\dot{\beta}}$ $C_{Lq}+C_{L\dot{\alpha}}$ $C_{Yr}-C_{Y\dot{\beta}}$	$C_{lp,rot}$	C_{lr} C_{mq} C_{nr} C_{Lq} C_{Yr}	$C_{l\dot{\beta}}$ $C_{m\dot{\alpha}}$ $C_{n\dot{\beta}}$ $C_{L\dot{\alpha}}$ $C_{Y\dot{\beta}}$ $C_{Yp,osc}$	$C_{lr}-C_{l\dot{\beta}}$ $C_{np,osc}$	$C_{np,rot}$ $C_{Yp,rot}$
RIGIDLY FORCED OSCILLATION		■		■	■	■	
AMPLITUDE STABILIZED OSCILLATION FREE OSCILLATION ELASTICALLY FORCED OSCILLATION		■					
"CROSS" OSCILLATION						■	
RIGIDLY FORCED ROTATION ROLLING FLOW	L		■				■
FREE ROTATION			■				
WHIRLING ARM CURVED FLOW	L L			■			
PARALLEL FLOW OVER DISTORTED MODEL			■	■			■

NOTE: (1) SYMBOL "L" INDICATES LOW SPEED APPLICATION ONLY
(2) SUBSCRIPT "osc" DENOTES OSCILLATORY ROLLING DERIVATIVES AND SUBSCRIPT "rot" DENOTES ROTATIONAL ROLLING DERIVATIVES

Figure 18

Wind tunnel methods available for determination of particular dynamic derivative

approximately the same. In some cases, more than one test is required to determine a given derivative by a given method, as in the case of dynamic force derivatives (such as $C_{Lq} + C_{L\dot{\alpha}}$) which can be determined by, for example, the free oscillation method if tests around two parallel axes are performed. Furthermore, in the case of the method of "cross" oscillation we have the requirement that the corresponding oscillatory damping derivative is known.

Examining the diagram in Figure 18 it appears that the method of rigidly forced oscillation is the most useful of all, permitting determination of all the derivatives except those due to rotational roll. It should therefore be recalled that three different variants (requiring quite different experimental set-ups) of this method are needed to accomplish this; namely, one using angular oscillation, one using translational oscillation, and, finally, one using a combination of the two which may be called "snaking" oscillation. These three variants require, however, basically the same type of data analysis and are therefore presented under a common heading.

It should be noted that the methods using rolling or curved flow or whirling arm are only applicable to low speed work, and that the method of rigidly forced oscillation, at least that part of it which requires the balancing of inertia effects, may present large difficulties when used with higher frequencies which is often necessary in high speed work.

The diagram in Figure 18 is intended to serve as an indication of which wind tunnel method or methods it is possible to use for the determination of a given derivative. The schematic drawings (Figures 6 to 17) can then give the main aspects of methods of interest, from which the choice of method may be made on the grounds of availability of experimental equipment and test conditions required. Finally, the detailed information about the method selected may be found in the reports listed in the relevant part of the bibliography[a].

APPENDIX

STABILITY DERIVATIVES

The stability derivatives are usually presented in the form of non-dimensional coefficients. Here are the most common of them, in standard American notation:

Static longitudinal derivatives

- $C_{m\alpha}$ pitching moment due to angle of attack
- $C_{L\alpha}$ lift force due to angle of attack

Static lateral derivatives

- $C_{n\beta}$ yawing moment due to angle of sideslip
- $C_{l\beta}$ rolling moment due to angle of sideslip
- $C_{Y\beta}$ side force due to angle of sideslip

Dynamic longitudinal derivatives

- $C_{m\dot{\alpha}}$ pitching moment due to vertical acceleration
- C_{mq} pitching moment due to pitching
- $C_{L\dot{\alpha}}$ lift force due to vertical acceleration
- C_{Lq} lift force due to pitching

Dynamic lateral derivatives

- $C_{n\dot{\beta}}$ yawing moment due to acceleration in sideslip
- C_{nr} yawing moment due to yawing
- C_{np} yawing moment due to rolling
- $C_{l\dot{\beta}}$ rolling moment due to acceleration in sideslip
- C_{lr} rolling moment due to yawing
- C_{lp} rolling moment due to rolling
- $C_{Y\dot{\beta}}$ side force due to acceleration in sideslip
- C_{Yr} side force due to yawing
- C_{Yp} side force due to rolling

In case of oscillatory motion around a fixed axis the effects of translatory acceleration (= rate of change of angle of attack or angle of sideslip) and rotational velocity are present at the same time, which gives oscillatory derivatives such as $(C_{mq} + C_{m\dot{\alpha}})$ and $(C_{Lq} + C_{L\dot{\alpha}})$ in case of oscillation in pitch, and $(C_{nr} - C_{n\dot{\beta}})$, $(C_{lr} - C_{l\dot{\beta}})$ and $(C_{Yr} - C_{Y\dot{\beta}})$ in case of oscillation in yaw.

The derivatives are usually made dimensionless in such a way that

$$C_{m\alpha} = \left[\frac{\partial C_m}{\partial \alpha}\right]_{\alpha \to 0};\quad C_{Y\beta} = \left[\frac{\partial C_Y}{\partial \beta}\right]_{\beta \to 0};$$

$$C_{nr} = \left[\frac{\partial C_n}{\partial \dfrac{rb}{2V}}\right]_{r \to 0};\quad C_{L\dot{\alpha}} = \left[\frac{\partial C_L}{\partial \dfrac{\dot{\alpha}c}{2V}}\right]_{\dot{\alpha} \to 0}$$

and so on,

where $C_m = M/\bar{q}Sc$ = pitching moment coefficient
$C_L = L/\bar{q}S$ = lift force coefficient
$C_n = N/\bar{q}Sb$ = yawing moment coefficient, and so on

with α = angle of attack
β = angle of sideslip
p = rolling velocity
q = pitching velocity
r = yawing velocity
V = air speed
$\bar{q}$ = dynamic pressure
S = reference area
c = reference length in longitudinal motion
b = reference length in lateral motion

A dot over a symbol indicates differentiation with respect to time.

[a]To reduce the length of this article, the bibliography has been omitted. The reader is referred to National Research Council, Aeronautical Report LR-254, on which this paper is based.

FUTURE USES OF SPACE VEHICLES†

by K. J. Radford*

Royal Canadian Air Force

INTRODUCTION

THE purpose of this paper is to discuss the uses to which space vehicles may be put in both the civil and military fields in the next decade. This is a very large subject and my coverage of each facet will necessarily be brief. However I hope that I can bring to the fore those applications which I consider will be important in the years to come and at the same time put some of the more sensational suggestions into perspective.

In dealing with space vehicles it is convenient to consider them in three categories, specified by the final velocity achieved after boost:

Sub orbital velocity — missiles

Orbital velocity — satellites

Escape velocity — space vehicles

The dominant feature of vehicles with less than orbital velocity is, of course, that they fall back to earth, and this is exactly what is required in a missile. The time that such vehicles spend above the earth is naturally limited, with typical values between 15 and 30 minutes. This short time of flight limits the usefulness of this class in more routine operations such as communications and meteorology, but such vehicles may have a minor part to play in roles other than as missiles.

The second class includes all vehicles which attain the velocity required to orbit the earth. Orbiting vehicles enjoy comparative freedom from the restrictions in line of sight communications and data gathering which are imposed by the curvature of the earth. In this respect also, the rules of sovereignty of air space have not yet been extended into space, so that US satellites can pass over the USSR, and vice versa, without challenge or protest at the present time. This situation may change when a satellite with an overt military application is launched, but declarations of sovereignty will not be of much use unless the means to enforce them are available. Satellites travel outside the earth's atmosphere and, more important, above the portion of the atmosphere which causes severe attenuation of high frequency radiation, like infra-red. Satellites may therefore carry equipment which can be expected to have very long detection ranges on infra-red sources above the attenuating portion of the atmosphere (above 30,000 ft to 50,000 ft); and also to absorb and use radiation from the sun which would otherwise be absorbed or reflected by the earth's atmosphere, as for example in the use of solar energy cells. Finally it is possible to look down on the earth from satellites from a height which can never be achieved by airborne vehicles, thus allowing a much greater field of view and also permitting observation of phenomena which occur only at these greater heights, such as the plume of a rocket engine as it becomes visible above the tropopause.

The third class embraces vehicles which attain sufficient velocity to escape from the earth's gravitational field and take off into the wide blue yonder — or more correctly the wide black yonder. These are the vehicles which will eventually be used for exploration of the moon and the planets, and which are some years behind those used for placing satellites in orbit. Nevertheless the first simple vehicles have recently escaped from the earth and are at present orbiting the sun. These early extraterrestrial voyages are undoubtedly the forerunners of manned exploration and exploitation of our neighbours in the solar system.

I will now proceed to discuss the applications of these vehicles to the tasks which confront us in both the military and civilian spheres.

MILITARY APPLICATIONS

Dealing first with the military, I think it is widely recognized that the present capabilities of ballistic missiles in offense far outweigh those of the defence against them. This superiority of offence over defence is likely to exist for some time to come. The best defence against ballistic missiles is to destroy them on their bases or to destroy the means of launching them, and this puts a nation which is dedicated to a "strike second" posture in a most difficult position. The fact that the enemy can strike first requires that missiles required for retaliation must be defended. In the absence of effective active defence, the only means left for protection of the retaliatory force are passive — protection by concrete, concealment and dispersal. The underground Atlas sites, the mobile submarine launcher for Polaris and the development of the mobile Minuteman are evidence of the existence of this situation.

There have been suggestions from many quarters that the requirements for dispersal and some reduction in vulnerability could be achieved by placing vehicles in orbit such that they could be launched at earth targets on command. This scheme has the advantage that the prime deterrent targets in any nuclear exchange would be remote from the homeland. There is a penalty involved in this plan, which arises from the fact that it takes a similar amount of energy to get a missile down from orbit as it does to get it up, and each of these amounts is probably greater than that required to hurl a

†Paper read at the Annual General Meeting of the C.A.I. in Ottawa on the 24th May, 1960.

*Director of Systems Evaluation

warhead between two earth locations. Adoption of the idea would therefore entail greater investment per missile on target. However, the greatest argument against such a system is that the concealment attained is less than that with a nuclear submarine or a site in Siberia, for example. Objects in orbit are on precise courses which can be predicted with some accuracy. With time available in which the orbiting vehicle could be tracked on successive passes, and once the vehicle is identified as hostile, it seems that it might be possible to intercept and destroy or disarm such a device. Add to this the uncertain effect of establishing such a system on world opinion, the problems of servicing over a prolonged period and the possibility that someone might learn the code and fire them at you, and the missiles in orbit idea does not seem as attractive as at first sight.

One stage further leads us to the suggestion of establishing missile bases on the moon, and the intriguing argument that with flight time to the moon in the order of days, there would be plenty of time to launch the retaliatory missiles after the attacking force had been detected heading for the moon base. However, the problem would remain of deciding whether the vehicle heading towards the moon was hostile or just another space probe, and there would be a considerable chance of launching the retaliatory force from the moon after mistaking the intentions of a space vehicle approaching the base. Moon bases would require a manifold increase in investment in the deterrent. Right now, the possibilities of protection concealment and dispersal of earth deterrent bases seem far too good to allow the moon base concept to go ahead. But should conditions here on earth change, this is a proposal which should at least receive some consideration.

At this stage, let me say a few words about the view held in some quarters that space will become a major battlefield in any future war. I think that we are past the stage when wars can be decided by individual combat between champions in a place remote from the homeland of the nations involved. It seems to me that a battle between space forces could be decisive only if the victory allowed one combatant to dominate the earth by virtue of his control of space, and thereby to bring destruction to the opponent's homeland without fear of retaliation. We are a long way from that state of affairs now, but this is the danger of which we must be constantly aware.

To summarize this aspect of military affairs, the earth launched ballistic missile would seem to fulfil requirements for offensive and deterrent forces for many years to come. Space based systems do not appear to offer operational advantages at the present time, and would almost certainly be very much more costly.

Earth satellites have some potential in the very difficult problem of defence against the ballistic missile, by virtue of the fact that they can operate in a region where there is little attenuation to very high frequency radiations such as infra-red. This feature together with the wide field of view obtained from satellite altitudes makes feasible a system to detect hot objects such as rocket motors as they rise above the tropopause. The development of such a warning system into one for intercept and destruction of the warheads is clearly something we should explore.

CIVIL APPLICATIONS

Turning now to less fanciful matters, there are a number of everyday operations which will be facilitated in the next few years by the introduction of earth satellite systems. Specifically these are:

(a) communications,
(b) navigation, and
(c) meteorology.

Communications

Satellite relay systems offer two advantages over ground based equipment for long range communications:

(a) long range can be obtained using line of sight frequencies, due to the altitude of the satellite above the earth, and

(b) long range transmissions, which are now affected by ionospheric disturbances, can be made much more reliable, since the very high frequencies used in line of sight transmissions are relatively unaffected by natural phenomena.

The number of satellites required in a communications system depends upon their altitude; the problem of determining the number required is complicated by the different motions of the earth about its axis and the satellites in their orbit. The orbital period of a low altitude satellite is considerably less than that of the earth's rotation, so that when a satellite of 2-hour period (for example) returns to the same place in its orbit after one revolution, the earth locations which it is attempting to link will have effectively moved 30° in longitude. The link must therefore be maintained by a preceding or succeeding satellite in the same orbit, or possibly by satellites in another orbital plane. To overcome this problem, the ultimate development in a satellite communications system would employ satellites with orbits in the equatorial plane and with a 24-hour period. Such satellites would appear from the earth to hover over one point. The 24-hour period can be attained only by satellites at an altitude of 19,500 nautical miles above the earth, and large boosters will be necessary to place significant payloads in orbit at that altitude. A minimum of three ground stations would provide world-wide coverage, and it has been suggested that a first use would be for trans-Atlantic communication. This system would be capable of transmitting television programs and other high quality information.

It is an interesting fact that the installation period and the initial capital cost of a system employing three synchronous satellites compare very favourably with other more conventional systems. Moreover, the operating cost of the synchronous satellite system will be competitive with other means of communication such as submarine cables.

The first test of a US developed, synchronous satellite system will be in 1963, and it is to be expected that reliable communications will be established late in 1964.

Navigation

When the first earth satellites were launched, a number of groups reported measurements of Doppler shift of the radio transmissions from the satellites, and deductions of orbit parameters from them. A group at the Applied Physical Laboratory, Johns Hopkins University,

proposed that such a procedure, worked in reverse from known orbit parameters, could be the basis of a position fixing system. The apparent increase, null, and decrease in the received frequency as the navigation satellite transmitter approaches, goes overhead, and recedes makes it possible to determine the relative position and motion of the satellite and observer. The US project "Transit" is designed to establish a navigation system using this principle in the first instance, with development leading to a system in which satellites transmit such information as identification and time and a principle similar to astronavigation is used.

The accuracy of navigating by Transit will vary with the accuracy of observing the satellite position, the computing procedure, and will also be directly related to the known orbital characteristics. No figures of expected accuracy are available as yet, but it is likely that position fixing to less than one mile will be possible in the final system, with relatively simple ground or airborne equipment. This system will undoubtedly be of importance for airborne and surface navigation in the near future. It may have particular application for navigation in Arctic regions.

Two Transit satellites have been launched to date. Transit I (a 36-inch, 265 lb, non-miniaturized test vehicle) was launched by a Thor Able booster on the 14th September, 1959, toward a 400-mile orbital altitude. Owing to the failure of the separation mechanism, the final stage was not effective, and the satellite fell into the Atlantic off the coast of Ireland. However during the short lifetime of the satellite, the John's Hopkins group made measurements which confirmed a predicted fixing accuracy of considerably less than one mile from a fixed ground station. A second satellite duplicating Transit I was launched on the 13th April, 1960.

Meteorology

Earth satellites, travelling outside the atmosphere and equipped with suitable sensors, offer an unique opportunity to observe the phenomena which control the weather. Initial observations of cloud cover and movement have already been made and these data should allow some estimates of wind force and direction to be made. As suitable equipment becomes available, a three-dimensional distribution of temperature and water vapour at all altitudes can be obtained. With suitable infra-red sensors, the temperature and quantity of gases, such as carbon dioxide, in the atmosphere, can be measured, and this will lead to a better understanding of the circulation of air currents which have a direct effect on weather conditions on earth.

While measurements are continually being made from instruments installed in satellites and rockets on a space-available basis, the US satellite TIROS is equipped with infra-red detectors and television. Later models will contain a light-weight radar to measure precipitation. In the first model launched on the 1st April, 1960, the images from two TV cameras are scanned, stored on tape and read out to ground stations at Hawaii and Fort Monmouth, N.J. In operational use, the production of finished prints on the ground will be the start of a complex operation to provide usable data to local forecasters. The US weather bureau is responsible for this important phase.

SPACE EXPLORATIONS

I come now to the subject of space exploration and the usefulness of activities outside the immediate vicinity of the earth. At the present time I cannot predict any major military role for man in space. In saying this, I do not wish to exclude the possibility that one may develop, but merely that it is in my view too early to be specific about the military role in space. This is an area where constant attention is necessary because, as I mentioned earlier, we could not permit another power to reach the point where it could control activities on earth from a position in space.

Although we cannot specify at the present time any major military role for man in space, I consider that the projects aimed at manned space exploration must continue; firstly because it is not in the nature of man to neglect this challenging opportunity and, secondly, because the advances in scientific research which will result from this exploration will ultimately be of great benefit to the human race.

CANADIAN PARTICIPATION

The great cost of supporting many of the programmes which I have mentioned makes it most desirable that Canadian participation in this field should be on a co-operative basis with the US or within the Commonwealth. Although the advances required in such areas as propulsion can probably be financed only by the major powers, there are many less spectacular developments which will be vital to the success of the projects and may well be within the scope of Canadian effort. For example, on-board electronic equipment and auxiliary power units will be needed which must necessarily be light yet high powered. They must also be able to withstand radiation and to operate in an environment far different from that on earth. Also, new materials will be needed for a wide range of applications, such as propellants, combustion chamber linings, low temperature hydraulics, vehicle skins etc. Canada could find ample opportunity for exercising her scientific talent in these associated fields.

CONCLUSION

In conclusion, therefore I would make the following points:

(a) The earth launched ballistic missile would seem to fulfil requirements for offensive and deterrent forces for many years to come. Space based systems do not appear to offer operational advantages at the present time and would almost certainly be very much more costly.

(b) The use of earth satellites in a system for defence against the ballistic missile is worth exploring.

(c) Earth satellites will become useful in the fields of communications, navigation and meteorology in the very near future.

(d) No major military role for man in space can be specified at the present time, although this is an area which requires constant attention.

(e) Manned space exploration must continue because great benefit will ultimately result to the human race.

(f) Canada should participate in space projects on a co-operative basis with other nations and there are many vital areas in which she can exercise her scientific talent.

VERTICAL FLIGHT CONTROL BY PRESSURE ALTITUDE — A REVISED SYSTEM OF ALTIMETRY†

by S/L W. R. Fryers*

Royal Canadian Air Force

THERE comes a time for re-thinking through most of Man's affairs, however sacred or fundamental they may seem. This time comes often in these days of desperate progress. Perhaps the time has come for re-thinking and revising our system of altitude control.

Our present system defines altitude in terms of linear measurements — usually in feet above sea level. Altimeters are designed to indicate height in these terms. This was a logical approach when aviation was just getting off the ground. Separation from the ground for brief, low-level flights was the paramount consideration. For this, linear units were handy, useable and well-understood. Traffic problems were something for the future.

The traffic problems are here and now. Moreover, present trends suggest immensely greater air traffic in the not-distant future, especially in the light and medium category, operating mostly at lower levels. Ever greater numbers of non-professional pilots will crowd our air-space aided by the universal use of auto-pilots and other refinements in equipment. Greater utilization of available air space even now awaits a system of secure guidance. Various elaborate schemes are being used, tested or designed to aid control of aircraft in one, two or all three of the dimensions in which they can move.

Relative position in the vertical by pressure indication is by far the most universal and precise control available to us. An ordinary serviceable altimeter will respond to an altitude change of 10 ft. Accuracy to within 50 ft is normally attained. By comparison, all other measures of position in space are either very local in application or very coarse in indication, or both.

But by a tradition based on the ground-bound origins of aviation, we still prefer to try measuring vertical position in terms of feet, metres or some such linear unit, by means of the conventional altimeter, a pressure actuated instrument. In so doing we lose much of the accuracy possible in vertical spacing and altitude control. Due to continuous fluctuations in atmospheric conditions, linear altitude is not readily measured, in spite of elaborate instruments and frequent corrective measures by the pilot. The net result is less accuracy, less safety, less available air space and unnecessary complication in navigation procedures. Increasing traffic density must presently force us into greater exploitation of our useable airspace — especially in the vertical dimension. This, we contend, must be done by converting over to a universal system of pressure altitude flying from the ground up.

PRESSURE ALTITUDE SYSTEM

We can convert to a system of vertical flight control by simple pressure altitude rather easily. The basic instrument of altitude control would be the Pressure Altitude Indicator (PAI), in lieu of the present altimeter. It is a similar instrument, with the scale reading in pressure units instead of feet. However there would be no altimeter settings, variable scales or adjustable hands in this basic instrument. This is an important difference from the conventional altimeter. It would be tamper-proof to assure universal uniformity in every aircraft at all times.

Deferring, for the moment, the argument on the soundness of using absolute pressure measurement for the control of flight in the vertical dimension, we can consider the question of which pressure unit should be used, and, for the purposes of illustration, a typical instrument. (Of course many types of instruments are possible, and the ultimate form of presentation is outside the scope of this paper.)

PRESSURE UNIT

For this unit we propose the millibar. It is an obvious choice, as it is a universal measure already in widespread use. The total range will be from sea level pressure (as high as 1050 millibars) up to say 50 millibars (approx. 67,500 ft) — a total range of 1000 millibars. This covers the effective range of most airborne craft. This also leads us to the desirable position of being able to use dial scales divided into units and multiples of ten.

THE INSTRUMENT

Precise indications over a range of 1000 millibars requires three scales and three indicating hands; one for units reading up to ten, one for tens readings up to 100, and one for hundreds reading up to 1000. This unit scale may be marked to half divisions (half of one millibar), equivalent to about 15 ft of altitude at sea level. The

†Submitted 11th February, 1959.
Revised 24th August, 1960.
*Senior Meteorological Officer

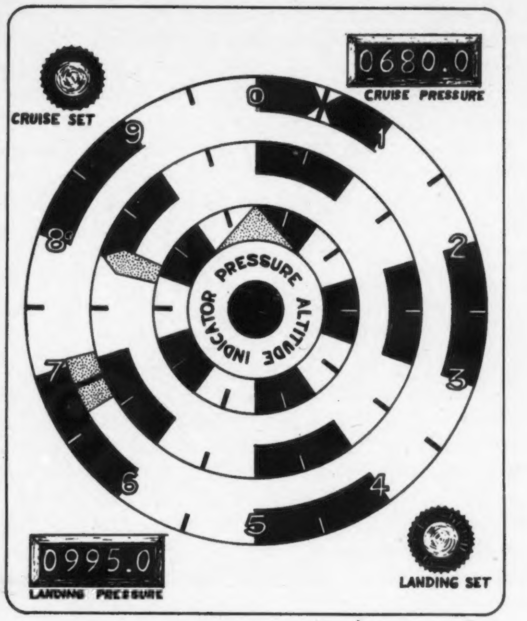


Figure 1
Pressure altitude indicator

scale would be easily readable to half this interval, that is, to about 7 ft. Further precision is neither necessary nor practicable.

The ranges of the three scales of the PAI would be as follows:

Units scale	300 ft approximately, at msl
Tens scale	3000 ft approximately, from msl
Hundreds scale	67,500 ft approximately, full range.

For comparison the conventional altimeter's scales have ranges as follows:

Units scale	1000 ft approximately, at msl
Tens scale	10,000 ft approximately, at msl
Hundreds scale	100,000 ft approximately, full range.

Design suggestions

The decreased range and consequently increased sensitivity of the units scale of the PAI permits us (even compels us) to reduce it in size and place it in the centre of the instrument. This reduces the movement of the indicator hand under conditions of turbulence and fast manoeuvres, and improves readability. A scale circle of 1.5 inches diameter gives good presentation (Figure 1). The principal use of this indicating hand is for precision flying under instrument flying conditions.

The tens scale is displayed on a 2.5 inches diameter circle. This size corresponds to the scale of the conventional altimeter. On the PAI this scale could be marked in red, or otherwise accentuated. For most air operations this would be the only scale in continuous use.

Finally, the outer scale, indicating in hundreds, is displayed on a 3.5 inches diameter circle. The indicating hand in this case is of the 'flag' type, 0.5 inches wide, as precision reading is not required. It is principally a 'zone' indicator, as each division covers at least 3000 ft, low level, and up to 10,000 ft at high levels.

The scales themselves can be designed to read in right or left progression. The usual numbering would show increase in number magnitude in clockwise rotation. During ascent the hands would move counter-clockwise, opposite to the present altimeter. However, no serious difficulty is expected from this feature, the pilot adapting himself to the change quickly and easily.

LANDING PRESSURE SCALE

The instrument so far described is a complete PAI suitable for any type of flying; instrument or visual. It is a simpler mechanism than the present altimeter, which it completely replaces. However, in practice, it is possible that various refinements to aid the pilot might be added. For instance, a landing pressure indication would be very useful, if not essential. Adjustable by a thumb knob on the front of the instrument (shown in lower right corner of Figure 1) a sub-scale (lower left corner of Figure 1) would show the current station pressure (QFE) of the destination airport. Note, however, that the hands and scales of the basic instrument are not involved in this setting. As a further refinement a special landing pressure scale could be utilized, superimposed between the units and tens scales and coupled to the landing set knob. Such a landing scale, covering the last 50 millibars of descent, is shown in Figure 2. With markings etched on a clear plastic overlay and side-lighted when in use, it would not interfere with the basic instrument. Zero on this scale would be set for station pressure (QFE) of the destination airport. The tens hand would then point to the 'pressure interval to go' during a landing approach, and landing would be made at zero reading.

CRUISE PRESSURE INDICATOR

Another refinement which may be suggested is a cruise pressure (level) indicator, re-settable by a thumb knob (see upper right and upper left corners of Figure 1). There would be no indication on the scales of the instrument; simply a number in a window.

OPERATIONAL TECHNIQUES

Given such an instrument, it is now necessary to consider the techniques involved in its use.

The pressure altitude system requires that flight levels be defined and invariably stated in terms of pressure. The initial strangeness in using and appreciating

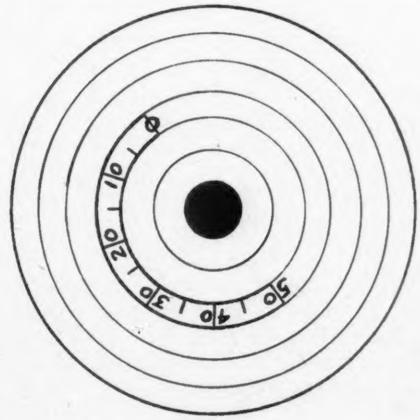


Figure 2
Landing scale overlay

pressure units would quickly pass. Safe separation intervals may be determined by careful investigation. Under many circumstances a vertical separation of 10 millibars could be considered safe (this is equivalent to about 300 ft at low levels, increasing to around 1500 ft at high levels). Separations for IFR traffic operating in difficult conditions of turbulence could be arbitrarily increased according to the situation.

Landing problem

The landing problem looks difficult, but need not be. The simplest approach is, of course, the visual approach. An example will illustrate: Pilot obtains the landing pressure (station pressure, QFE) from the destination airport by radio. If he intends to join the circuit at the usual 1000 ft level he will descend to a reading of the station pressure less 30 millibars. Continuing to final landing, the pressure altitude indicator will then read the station pressure.

To aid IFR approaches, flight levels and elevations in the manoeuvring area around an airport would be designated as 'ADP' pressures (Above Datum Point), distinguishing them from the absolute pressure levels in use generally at higher altitudes. Thus, for instance, on an ILS approach, interception of the outer marker would be made at 50 millibars ADP (about 1500 ft above ground). Pilot would continue with procedure turn at 50 millibars ADP until glide path is intercepted. Descent is continued to authorized, minimum approach altitude, say 10 millibars ADP (300 ft approx.). If not visual, missed approach procedure is instituted. The carrying out of the precise IFR approaches would be greatly aided by use of a landing scale such as described above, showing progress on the last 50 millibars of descent (about 1500 ft), landing finally to zero reading.

Terrain clearance problem

Terrain clearance would seem to be another serious difficulty under the pressure altitude system, but this too resolves upon examination. Again, an example will help to illustrate. Aircraft must clear terrain indicated on route chart as having a peak elevation of 9880 ft above msl. Pilot refers to a conversion table relating elevation and pressure altitude (available on computer, or on navigation charts or permanently affixed to instrument panel) and notes that the standard pressure at this level is 700 millibars. He selects a pressure level suitable to his direction of flight, some 30 to 50 millibars higher according to circumstances; i.e. he continues flight at 650 millibar level. Allowing the conventional 30 ft height difference per millibar of pressure difference, the clearance here provided is 1500 ft. In current practice, minimum flight altitudes on airways are pre-determined and pre-printed on aeronautical charts. These could as easily be given in millibars as in feet, with no loss of definition.

Off airways, the pilot must select a suitable pressure level for safe clearance, again making the simple elevation-to-pressure-level conversion. If there is a nearby weather station to provide current pressure readings, more precise clearance can be computed. The procedure is similar to present techniques, and just as simple.

Atmospheric pressure variations

Basically the problem of terrain clearance, like the landing problem, exists because of the hourly and daily variations of meteorological conditions. Those vast eddies, the high pressure and low pressure weather systems drifting across the country, are continually lifting and lowering the various pressure levels of the atmosphere and, in extreme cases, changing them by several hundred feet in a day. This results in errors in our present altimeters, which are, of course, pressure actuated instruments.

Corrections for pressure variations

To help in correcting these height errors due to atmospheric pressure variations, our network of weather stations, 100 to 150 miles apart on airways, measure the surface pressure hourly. A derived figure, known as the altimeter setting, is then distributed each hour by teletype and broadcast by radio to the pilot in the air. The pilot re-sets his altimeter by uncoupling the hands from the pressure capsule and re-positioning them on the linear height scale, so that the new altimeter setting registers in the special sub-scale provided. This setting is then used for altitude control and terrain clearance until the next weather or radio station provides a new setting.

The proposed pressure altitude system would require that weather stations provide the station pressure (QFE) for use as a landing pressure, instead of the present altimeter setting (or Kollsman Number, QNH). This station pressure could also be used for terrain clearance by reference to a suitable computer scale relating height and pressure. Or, more directly, the weather station could provide the pressure difference from normal for broadcast. Either of these systems would serve the purpose of providing terrain clearance. These simple procedures will accomplish the object of terrain clearance just as easily and accurately as methods used today.

It might be argued that because all terrain heights are given in terms of feet (or metres) above sea level on maps and such, this presents a unique difficulty with the pressure altitude system. We should remember however that the present altimeter is just a pressure actuated instrument, and that the height indications from it are subject to various and often arbitrary corrections. These corrections have not always been successful in providing terrain clearance, as the record shows. In both the present and the proposed systems of altimetry, a correction must be made to allow for variations from standard pressure in order to provide precise terrain clearance. There is every reason to believe that a carefully selected pressure altitude would provide even more safety than present procedures.

For flight planning purposes, height variations for various pressure levels are readily available from the weather office, where they are routinely plotted on constant pressure charts. These upper level charts cover most of the earth's surface and are renewed twice daily.

Circuit procedure

What about circuit procedures? No difficulty! For example: "Set zero on the landing pressure scale to current station pressure (QFE) on the pressure altitude indicator. Take off and climb straight ahead to plus 15 millibars on the landing scale, turn left, continue climbing

to plus 30 millibars on the landing scale, level out and maintain this as circuit height". Roughly this gives the first turn at 450 ft, and circuit height at 900 ft. The millibar figures will quickly gain meaning in use.

The foregoing part of this article has presented briefly a pressure altitude system of altimetry, the instrument and the techniques. It remains to be considered whether such a system is necessary or desirable and why.

TRADITIONAL RESISTANCE

Pressure altitude flying is not exactly new. ICAO in a 1956 publication[1] recognizes that the altimeter "could have developed as a simple, absolute pressure gauge calibrated in . . . . millibars . . . . (although) the user would have had to learn to associate units of pressure with vertical distances. To eliminate the need for such mental conversions on the part of the pilot, the pressure actuated instrument was calibrated to provide an indication of vertical distance". But we find this same pilot now interpreting speed in terms of Mach numbers, engine power in inches of manifold pressure and so on. New units come into use almost daily in our technological society. More easily than most, the pressure level equivalents of height, aided by direct visual interpretation, would be quickly appreciated by the pilot. Is it to *tradition* alone, then, that we must sacrifice full utilization of pressure for vertical control?

COMPROMISE EXPEDIENCIES

Even now vast unpopulated areas of the earth's surface, plus ocean areas, are being set apart as 'standard pressure regions', where the sub-scale of the altimeter is set to 29.92 inches (msl pressure for standard atmosphere) as a constant fixed setting. So too are some subtropical areas such as Spain where meteorological conditions are relatively stable[*]. In effect this becomes pressure altitude flying, although the altimeter indication is in feet and all planning is in feet; millibars would serve equally well.

Moreover ICAO, in the same publication[1], recommended the standard pressure system (using QNE) for control of flight levels for IFR traffic on domestic airways above arbitrary transition levels. This establishes the equivalent of pressure altitude flying for some of the aircraft for some of the time. It leaves unresolved a variety of conflicts resulting from the variable-setting characteristic of present altimeters. At the same time they introduced a new system of units known as flight levels, similar to but not the same as linear altitudes. For example by this method, when the altimeter sub-scale is set to 29.92 inches, an indication of 2000 ft becomes known as flight level 20. Widespread adoption of the system is still pending.

And so in piece-meal, back-door fashion we approach the pressure altitude system for vertical flight control, but, falling short, we permit navigational confusion and wastage of air space to continue unabated.

---

[*]Since this was written the flight level system has been introduced for IFR traffic in both America and Europe.

INADEQUACIES OF THE ALTIMETER

Defence of the conventional altimeter system is mainly based on the idea that it tells height. This it almost never does. It is a pressure instrument and can only respond to pressure change. The height scale built in to the altimeter is a pure convention, based on a hypothetical "standard atmosphere" (and there are several of these – similar but not identical). A precise standard atmosphere probably never occurs. It is most nearly approximated at about Latitude 45° under ideal meteorological conditions, when perhaps a couple of times a year the surface temperature, lapse rate aloft, pressure and humidity approximate the definition. At all other times, all other seasons, all other latitudes, there are varying degrees of error in this height scale. We try to correct for transient changes of surface pressure by the altimeter setting system. This results in an arbitrary step-up, step-down change applied at all levels aloft. It is, moreover, applied by only some of the planes, some of the time. Airlines make their change in altimeter-setting at arbitrary geographical points along their routes. Errors are accumulated for 150 miles or so, followed by a step-up or a step-down. Other air traffic may or may not follow this procedure.

Similarly with the error due to the temperature of the air mass in which the plane is flying – in cold, denser air all pressure levels are lowered and compressed to a greater or lesser degree depending on the temperature; in warm air the reverse is true – a correction may be figured for this, say for terrain clearance, assuming an average temperature for the column of air below the aircraft. This, of course, will be an approximation. Careful navigators compute this correction periodically, and the altitude of the aircraft may be adjusted periodically as a result. Between corrections, the error accumulates. In most cases it is impossible for the single pilot to carry out a continuous program of altitude corrections.

REVISION OF FLIGHT ALTITUDE SYSTEM

It is somewhat in this manner, then, that we try to hold an aircraft at a flight level as indicated by a linear scale on a pressure instrument. We are using an arbitrary height figure derived by several computations from a simple pressure indication. The over-all result of such procedures is a rickety structure of flight altitudes, observed in greater or lesser degree by various airborne craft. It keeps everyone busy, especially the professional pilot and navigator. But it is not necessary, nor efficient, nor safe. A simple pressure reading from the same instrument will provide a flight level and traffic separation much better – without temperature compensations, computer-juggling, radio instructions, re-settings and all. For the first time, then, a designated flight level would be a world-wide, continuous smooth surface, constantly evidenced to *every* pilot without any manipulations on his part.

CONCEPT OF HEIGHT

Perhaps the conventional altimeter will be defended as giving a dimensional meaning to the height of an aircraft. As we have seen, this is very approximate. There are good reasons favouring the use of a unique unit of measurement for the 'up' dimension for aircraft, differentiating it from horizontal dimensions. The overwhelming

effect of gravity imposes an entirely different meaning, physically and psychologically, on this dimension. For most people, the linear sense of vertical distance fails utterly from a few feet above the ground. A city block of 1000 ft is comprehensible and within our physical experience. A similar height vertically is a vague unknown to all but experienced pilots and trained observers. Even to experienced pilots, the altimeter reading is usually little more than a number, related only to other similar numbers. Of course for earthbound forms and features, such as buildings or mountains, then we are obliged to use uniform linear measurements in all dimensions, to gain understanding of the inter-relationship of the parts. But our problem in aviation is much different. It concerns the movement of aircraft within the earth's variable, restless atmosphere. This problem lies within a separate frame of reference, and a new set of units for vertical position is acceptable here. Within this frame of reference – the useable atmosphere – horizontal distances are enormously greater than the vertical distances. The vertical dimension is entirely contained in the relatively thin layer of the atmosphere. Relative position in this limited dimension is, we contend, most easily and precisely determined by pressure indications.

OTHER CONSIDERATIONS

Many other aspects of the pressure altitude system could be mentioned if time and space permitted. In brief, some of these are:

(1) The millibar is the universal measure of atmospheric pressure, understood and accepted in all countries. Linear units, on the other hand, vary considerably from country to country.

(2) The pressure altitude scale is an expanding scale with altitude. A 10 millibar separation near sea level provides some 300 ft of separation, and at 45,000 ft nearly 2000 ft of separation. The scale thus automatically allows for the usual decrease in manoeuvring precision and for the coarser instrument indication which are characteristic of higher altitude operations.

(3) The normal tolerances on calibration of sensitive altimeters vary from about 15 ft at low altitudes, up to 300 ft or more at very high altitudes. Individual instrument errors could easily double these limits. By providing wider separations at higher altitudes, the pressure altitude scale protects against accidents due to this type of instrument error.

(4) Approach and landing procedures are greatly simplified due to the fact that landings are always made to zero reading on the landing pressure scale. In itself this is a notable safety feature of the pressure altitude system.

(5) Automatic devices for altitude control, carried inside the aircraft, would be simpler, cheaper and require less attention.

(6) Accurate data on flight levels and separations of all traffic for use by traffic control centres would be easier to obtain and use.

(7) Meteorological conditions aloft are normally analyzed and depicted in relation to constant pressure reference surfaces. This procedure is necessary for technical reasons. As a result, however, it integrates easily and naturally with a pressure altitude system of flight control, to the advantage of pilot and weatherman alike. All exchanges of information, including pilot reports to the weather office, cross-sections and forecasts to the pilot, would be facilitated by the use of this common system of units.

(8) Maps and charts would continue to have terrain heights indicated in feet above msl. By the addition of a printed conversion scale for relating standard pressure and height on every aeronautical chart, the pilot is assured of useable information for terrain clearance without the use of a computer. A computer allowing also for variations in surface pressures and air mass temperatures would provide greater precision, however.

(9) All the dynamics of flight are closely related to air density. Flight at a designated pressure level is made under more uniform conditions than would be the case when made at a designated linear altitude. This is a small but perhaps significant gain in assessing and predicting aircraft performance – an advantage to the flight engineer, the pilot, navigator and the aeronautical researcher.

(10) By eliminating the variable altimeter setting, the pressure altitude system will ensure the synchronization of all air traffic – IFR and VFR, Radio and Nordo aircraft, airway and quadrantal separations. Present procedures can never do this!

The full picture, for and against the pressure altitude system, cannot be presented here. It is one more device suggested for increasing air safety. It might easily double the capacity of our air space. It is our contention that such a system is entirely feasible, that it would represent a great step forward in safety and efficiency for air traffic, that it could be introduced without any great expense or upset to present organization. A full study of the system including instrumentation and techniques should be carried out by a suitable agency, and recommendations made by ICAO to member governments. It is almost inconceivable that the tremendous growth envisaged for general aviation can be handled safely by the present system of altimetry. To delay in facing this problem will be merely to compound the difficulty of eventual action.

ACKNOWLEDGMENT

The author wishes to express his thanks to Sgt. R. Parker for his help in the preparation of the Figures.

REFERENCE

(1) *Terrain Clearance and Vertical Separation of Aircraft,* ICAO Circular 26-AN/23, 2nd Edition, 1956.

C.A.I. LOG

SECRETARY'S LETTER

POST MORTEM

Last month I made a brief mention of the Joint IAS/CAI Meeting and the Canadian High Altitude Research Symposium, but my letter was written so soon after these events that I had not had time to think about them very much or to discuss them with anybody. We report on both in this issue; I think that they were an illuminating pair of meetings.

The attendance at the Joint IAS/CAI Meeting was most disappointing. Its programme included some very good papers but it failed to attract the audience that the papers deserved. If only 177 people can turn out when the Montreal Branch alone has over 500 members, something must be wrong. On the other hand the Canadian High Altitude Research Symposium attracted 81. It was a much less pretentious affair and dealt exclusively with a very specialized subject. But people came and the audience participation was excellent. Probably the fact that the Symposium did deal more or less with only one subject was the secret of its success. Good as they were individually, the papers presented at the Joint IAS/CAI Meeting were probably too diversified – except perhaps in the Telecommunications Session – to make it worth people's while to give up a morning or an afternoon or a couple of days to listen to them. At any rate that is our diagnosis of the trouble, and it will be noticed, from our announcements of the sessions planned for the Annual General Meeting in May, that the National Programmes Committee is trying a more closely related group of subjects for that occasion.

But our diagnosis may be wrong, and it would be very helpful if members would write to me to let me know why they personally did not attend the Joint IAS/CAI Meeting. Without such information the National Programmes Committee is just guessing, which is not the best way to effect a cure.

THE ROYAL CANADIAN NAVY

This year is the 50th anniversary of the Royal Canadian Navy and, as you will see, we publish in this, the last issue of 1960, a Guest Editorial by the Chief of the Naval Staff.

However some of us have been lucky enough to make some first hand contacts with the Navy this year, and certainly our eyes have been opened and our respect for naval aviation has been enormously enhanced. Last June nearly fifty of us from the Ottawa Branch visited the destroyer escorts HMCS Chaudière and HMCS Columbia at Kingston and went down the St. Lawrence on these ships as far as the Iroquois locks. From the 14th to the 18th November, CDR J. F. Frank visited the Vancouver, Calgary, Edmonton, Cold Lake and Winnipeg Branches, speaking on "Technical Requirements for the Operation of Aircraft at Sea". And on the 18th and 19th November the Test Pilots Section held a Symposium at RCN Air Station, Shearwater, which included a full day aboard HMCS Bonaventure at sea.

We will report on that Symposium in the next issue, when the photographs and notes have been sorted out, but I must say here that that day on the carrier was something that none of us landlubbers will ever forget. The weather was perfect; our hosts were perfect; and the flying . . . This is not just a matter of flying aircraft from the deck of a ship but rather an intimate blending of two machines and two crews into one unit, a ship armed with aircraft or an aircraft that can operate from the sea. And, with all respect to CDR Frank's talk to our western Branches, I think that only we who saw these operations off Halifax can have any real appreciation of how exacting the technical requirements are – and the flying requirements too for that matter.

HAPPY CHRISTMAS

In closing, on behalf of your Headquarters staff, I wish all our members and friends a happy Christmas and a satisfying New Year.

JOINT I.A.S./C.A.I. MEETING

Mr. D. R. Taylor, Chairman of the Montreal Branch, welcoming members to the first session.

THE series of Joint Meetings with the Institute of the Aeronautical Sciences was interrupted in 1959, when the Meeting was replaced by the Anglo-American Conference, and resumed this year on the 17th and 18th October in The Queen Elizabeth, Montreal. The technical programme consisted of four sessions, at which some very worthwhile papers were presented; as usual on these occasions the programme was divided roughly equally between Canadian and American papers. Total registration was 177.

THE DINNER

The Dinner, which was held in Le Grand Salon on the 17th October, was attended by 356 members and guests. Mr. Charles Tilgner, Jr., Vice-President, Eastern Region, and Mr. R. R. Dexter, Secretary, represented the IAS among those sitting at the Head Table. The President of the CAI, Mr. David Boyd, was in the Chair.

Mr. Boyd opened the proceedings by banging on the lectern with his shoe, in a manner that has recently become fashionable; this was a good start. In introducing the Head Table, he thanked Mr. Taylor, the Chairman of the Montreal Branch, for the excellent arrangements which had been made for the meeting and added a word of welcome to an old friend, Mr. J. C. Floyd, formerly Vice-President, Engineering, of Avro Aircraft Ltd., who was present in the audience on a short visit from England.

In his short address the President read a cable from Dr. E. S. Moult, President of the Royal Aeronautical Society, as follows:

> "Cordial greetings to the IAS and CAI on the occasion of your annual Joint Meeting. We wish you every success in your deliberations."

He also mildly chided the IAS at their change of name from "Aeronautical" to "Aerospace" and said, rather rashly, that the CAI would never change its name. In his reply Mr. Tilgner remarked that five years ago the IAS would never change its name; and it was generally conceded that Mr. Tilgner had had the better of the exchange. Mr. Tilgner expressed the regrets of Lt. Gen. D. L. Putt, President of the IAS, at being unable to attend and conveyed the greetings of the IAS to the gathering.

Mr. C. E. Tilgner, Jr., Vice-President of the IAS, addressing the opening session.

At the Annual General Meeting of the CAI in 1959, Air Commodore the Hon. J. A. D. McCurdy had been elected Honorary Chairman of the Test Pilots Section, and the Section had asked if they could take advantage of this Joint Meeting to present him with a Scroll to record the event. Accordingly the President called on Mr. R. J. Baker, Chairman of the Section, and in a brief ceremony Mr. Baker explained the signi-

Mr. F. T. Thurston, Principal Speaker, with Mr. David Boyd, President CAI

Presentation of the Scroll to Air Commodore the Hon. J. A. D. McCurdy by Mr. R. J. Baker, Chairman of the Test Pilots Section

ficance of the presentation, read the wording on the Scroll and presented it to Air Commodore McCurdy. In acknowledging it, Air Commodore McCurdy said how pleased he was to be associated with test pilots fifty years after his historic flight and reviewed the differences between test flying now and in 1909.

This presentation was followed by the Principal Address delivered by Mr. F. R. Thurston, Director of the National Aeronautical Establishment. His subject was International Collaboration. He started by reviewing the history of after-dinner entertainment, from dancing girls to court jesters, and then got down to the business of international meetings. He touched on some of the difficulties, such as language and security, and pointed out that the international exchange of information through the medium of technical meetings was becoming progressively less effective. Attendance at meetings all over the world was an expensive business and Mr. Thurston questioned whether the scientists and engineers were getting their moneysworth out of them. Yet, in the face of dedicated totalitarian competition, he said that effective procedures must be devised. He made some suggestions for the improvement of international committee work, principally that committees must be given very specific jobs to do and their terms of reference must include the dates of dissolution.

His address, though absolutely serious and raising a very fundamental question, was delivered with so much wit and with so light a touch that it was ideally suited to the occasion, an encouraging evolution of the tradition of dancing girls and court jesters.

At its conclusion, the President expressed himself as "speechless" and called on Dean Mordell to move a vote of thanks. This he did, drawing on his recent experiences at the Second Congress at Zurich and pointing out that Mr. Thurston had discussed a very serious problem, which was not disguised by the delightful way in which he had handled it. The Dinner was then adjourned.

TECHNICAL SESSIONS

The first session was opened by Mr. Taylor, who welcomed the members of both Institutes on behalf of the Montreal Branch, and he was followed by Mr. Tilgner bringing the greetings of the IAS. The final session on the Tuesday concluded with a few closing remarks by Mr. Boyd.

Members of the Montreal Branch have reported as follows on the sessions themselves:

Manufacturing and Testing Session: (l to r) Mr. C. E. Tammadge, Mr. I. R. Cameron, Mr. G. B. North and J. W. Ames (Chairman)

Morning Session, October 17th

MANUFACTURE AND TESTING

Reported by R. C. C. Ringrose and L. B. Clifford

The opening session of the joint meeting of the CAI and IAS was presided over by Mr. J. W. Ames of Canadian Applied Research, who, after a short opening speech, introduced to his audience his first speaker, Mr. C. E. Tammadge, Dynamic Test Engineer of Canadair Ltd.

Mr. Tammadge started his paper, "Some Techniques for the Ground Resonant Testing of Aircraft", by defining the aims of a resonant test; which are to determine the natural frequencies and the mode shapes of the aircraft. This gives the flutter speed of the aircraft and its dynamic response. The test results are used to verify the results obtained by calculations.

It has always been desirable to have the test results in the reduced form prior to flight of the aircraft. During the development period it is not always possible to reduce the data from the results very rapidly. In addition, modern methods of resonant testing have increased the testing time. This has tended to increase the delay between the prototype and the first production aircraft. Canadair has attempted to reduce the time required to obtain the reduced results, by adopting specialized equipment and revised testing techniques.

Principally the technique being used at Canadair presently includes the use of a large number of fixed transducers to measure the structural mode shapes. A semi-automatic polar recorder is used for plotting vector diagrams, and computing machines are used for the rapid reduction of test data. Slides were shown illustrating the use of these techniques in the Canadair CL-41 and CL-44 dynamic test programmes.

The second paper of this session, entitled "Manufacture and Testing of Black Brant Engines" was read by Mr. I. R. Cameron of CARDE.

Mr. Cameron gave a very interesting paper describing the production and test of the Black Brant engine as carried out at CARDE. The production facilities here are limited, but larger scale production could be undertaken by Canadian Arsenals Ltd. or other industrial sources.

The total process of manufacture is fully integrated, i.e. starting from the chemical polymer, from which the propellant is derived, and going through all the manufacturing phases until the final product is obtained and tested.

A brief history of the Canadian rocket propulsion programme was outlined, and also the reasons for the choice of a solid rather than a liquid propellant were given.

Descriptions and slides showing the various items of production used were presented, and emphasis was put on the air lifting of the propellant mixture from one phase of manufacture to another.

A discussion followed the paper and those present were interested to find that Canada was still in the rocket picture. The programme may not be as glamorous as the space programmes carried out by other countries, but a very valuable contribution is being made to our knowledge of the upper atmosphere.

The third speaker of this session was Mr. G. B. North of McDonnell Aircraft Corporation, with a paper on "Development and Check Out of the NASA Mercury Capsule".

The impressive feature of this paper showed up in what appeared to be an endless amount of testing. As the speaker proceeded with his presentation, outlining the large numbers of different tests being carried out, it became apparent that very little was being left to chance in the matter of proving the reliability of the various systems.

The speaker mentioned that the Mercury Project includes twenty capsules. Most of the development and qualification testing has been completed, including the first two launches of production capsules.

Prior to his discourse on the testing techniques, the speaker reviewed briefly the mission profile and flight systems. It was obvious, from the slides which were shown, that all the available space in the capsule is being utilized to the utmost. It was also apparent that a minimum envelope was used in the design of the capsule.

To provide Project Mercury with maximum reliability and minimum cost, the capsule systems incorporated existing hardware wherever practical.

The qualification requirements for Mercury were expanded beyond standard testing specification, including shock loads of 100g, vacuum conditions for systems operation and high acoustic noise functioning. Also aerodynamic tests were conducted in 24 wind tunnels, and the total test time was 3,400 hrs. Speed tests varied from low subsonic to Mach 21, and the models ranged in size from 2.2% to full scale. From these tests, static and dynamic stability, pressure distribution, heat transfer, airflow separation, vibration and flutter and escape rocket jet effects were evaluated.

Environmental control system tests were very extensive. The oxygen bottles working under 7,500 psi required much time to develop and qualify. Many hours of system operation were accomplished in altitude chambers. The pressure suit was subjected to several hundred hours of testing, including egression procedure development, heat chamber test, pressure suit evaluation, cockpit equipment development, main panel development and others.

Telecommunications Session: (l to r) Dr. J. H. Meek, Mr. R. R. Waer, Mr. I. M. Liss (Chairman) and Mr. R. Smelt

The capsule recovery system development included some 300 deployments. The system consists of a drogue chute with a 63 ft ringsail main chute; the main chute is 12% reefed for four seconds to prevent opening loads from exceeding a design limit. Considerable development time was required to determine the amount of reef, and a failure in the system results in a second chute being deployed.

Finally, the program will consist of a number of unmanned and primate flights prior to actually launching a manned flight. The speaker was not permitted to state a positive date for this flight, although he expressed the hope that it would occur early in 1961.

A movie in colour showing some of the test work being conducted on Project Mercury followed the talk. The movie helped to emphasize the need for such an extensive test program.

Afternoon Session, October 17th

TELECOMMUNICATIONS

Reported by E. R. Semple

Dr. J. H. Meek, Superintendent of Communications Laboratories, DRTE, Ottawa, was the first afternoon speaker. The interest of DRTE in all aspects of telecommunications and high altitude propagation phenomena is widely known now, as it has been pursued methodically by DRB since shortly after the war. Resulting from work by the Canadian team have been the JANET meteor-burst communication system and, more recently, Canadian participation in US satellite launchings, as well as a large number of Canadian investigations in long distance radio communication and interference phenomena. Dr. Meek and his group have had a large measure of responsibility for the success of these ventures.

Dr. Meek's paper, entitled "Long Range Communication with Aircraft", dealt with the problems of over-the-horizon telecommunication methods as applied to aircraft. The presentation was well illustrated with slides on the interference phenomena and their variation, choice of frequency and the factors affecting range and power transmitted. Canada is perhaps more concerned than other countries with disturbance phenomena because of their prevalence outside plus and minus 45° latitude (i.e. toward the poles). In aircraft communications over-the-horizon antennas appear to be the main problem.

In the question period enquiries were directed to Dr. Meek as to the usefulness of wire antennas today, the possibility of over-the-horizon communication for low-flying search and rescue helicopters, and the direction of future research. It appears that wire antennas have a long future because communication frequencies must be changed often for best transmission. In Dr. Meek's opinion helicopters might benefit from use of an ionospheric bounce type of communication, although transmission periods would be short and spaced by seconds or minutes; weight and volume limitations pose problems in helicopters. Research may improve utilization of over-the-horizon communication for aircraft, but the author stated that at present, when there are propagation disturbances, we have only a few vague rules and no pat answers.

The second paper entitled "The Development of a Global Communications Satellite System" by Dr. A. M. Levine, Vice-President, ITT Laboratories, Nuttley, New Jersey, was presented by Mr. R. R. Waer, Senior Scientist under Dr. Levine. Dr. Levine holds a number of important patents in the fields of communications and missile guidance. He has worked at ITT since 1942 on television and radio, and projects Meteor, Talos, Lacrosse, Bomarc, and more recently on satellite communications.

Mr. Waer used coloured slides in presenting the concept and specification of requirements for a global communications system, using three satellites in 24-hour equatorial orbit. In 24-hour orbit the distance to earth is 22,300 statute miles, so that beam width for full coverage need be only 17°. Actual area coverage with a 3-satellite system is only 88%, and excludes the two poles. Polar coverage may be obtained by orbiting three more satellites.

In the system design, the basic objectives were first laid out under the headings Life and Reliability, Sanctity and ECM, and Communication Subsystem, the latter of which was subdivided into Coverage, Capacity and Quality, Frequency, Satellite Transmitter, Power Output, and Ground Receiver Sensitivity. Roughly eight ground stations with fixed antennas would be required in each of the three stationary ground areas, with repeater stations on the overlapping fringe areas.

The author dealt with each of the steps in design, pointing out the chief problems associated with each.

In closing, Mr. Waer noted that before the orbital satellite communication system could be realized and used to its full potential as a peaceful tool, some clarification of the international "electropolitical" situation is required. Then such satellites may be used for mail, voice and telegram transmission as tools of peace.

In response to the question of economic feasibility, Mr. Waer noted that at least one group considers such satellites to be commercially feasible. Although all components can now be directly obtained, and in fact it is technically possible to put such satellites up within two years, the financing is more dependent on government rather than commercial or private interests. "Equipment itself is not the economic problem."

The third paper on telecommunications was presented by Mr. R. Smelt, Chief Scientist of Lockheed Missiles and Space Division. Mr. Smelt's experience with missiles dates back to 1940 with Naval Ordnance, where he became Deputy Chief of the Aeroballistics Department. At Lockheed he is adviser to management on missiles and space matters. The paper, originally entitled "Problems of Interplanetary Communication: Solar Orbiting Satellites" was put on a somewhat wider base by the author, under the title: "Some Aspects of the Space Communication Problem".

The author extrapolated from the development of typical earth-to-earth communication links of kilomegacycle frequencies to the problem of obtaining sufficient power at interplanetary distances, despite noise and interference effects from the atmosphere, sun and space.

Although the cost of solar cell power in the Discoverer series was only of the order $500 per watt, it still costs about $1000 for each pound of equipment in orbit. Nuclear power sources appear economic for powers above 1 kw, but pose other problems. In construction we are driven away from high power tubes and heat dissipating equipment because of both cost and reliability. Radiated powers may be of the order 1 to 10 watts from experience at present, certainly no more than 100 watts in a satellite.

Satellite vehicles have had non-directional antennas so far. Lockheed have focussed their attention on folding directional arrays. The author showed several original designs of folding antennas by Lockheed including their "tinfoil-on-plastic" type inflatable arrays, which once inflated remain rigid in space despite loss of inflating gas. Such directive arrays, together with a 600 ft dish, would provide a 10^4 increase in signal to noise level. The author showed diagrams of noise source levels and achievable noise figures at this point, and then summarized the practical problem with a table of information rates versus means of communication. The conclusion that interplanetary communication has a practical basis in low information rates (i.e. small bandwidth) was pointed out by the observation that a few basic signals per minute can give a fair amount of information in the space of hours or days.

As a last point the author illustrated a means for relaying signals around the sun's corona. It is the method of Trojan Points, discovered by Lagrange, whereby objects in a planet's own orbit are in stable equilibrium if situated at plus and minus 60° from the line drawn from the sun to the planet. The Trojan satellites of Venus were mentioned for example and also those of Jupiter. A satellite in either of these points might oscillate but would remain essentially in the fixed geometry. He noted also that Carruthers of Raytheon has recommended these points as "celestial junk piles" as well as communications satellite points.

Two queries on feasibility of optical interplanetary communications methods brought out that present detectors are not sufficiently sensitive, although radiated power may be of the order of kilowatts.

Mr. I. M. Liss of Litton Systems Limited, chaired the session.

Morning Session, October 18th

AERODYNAMICS

Reported by S. Bernstein

On the programme of this session, chaired by Mr. R. J. Templin, Head, Aerodynamics Section of NAE, were two papers on STOL aircraft and one paper on the subject of aerodynamics of blasts.

The first paper, "Design of an Inlet Duct for a Propeller-Turbine on an STOL Aircraft", was given by Dr. D. H. Henshaw of The De Havilland Air-

The audience at one of the sessions

Aerodynamics Session: (l to r) Mr. F. N. Dickerman, Dr. I. I. Glass, Mr. R. J. Templin (Chairman), Dr. D. H. Henshaw and Mr. C. F. Branson

craft of Canada Ltd. It discussed the special problems involved in the design of an inlet duct on an STOL aircraft, and described a simple and inexpensive electrolytic analogue method, which proved very useful in the design of the duct.

With STOL aircraft the engine must provide maximum possible power at the very low speeds used during takeoff, and in the design of the intake, which has an important influence on engine power, special attention must be given to the low speed, high angle of attack case as well as the high speed cruise case. It was shown that significant increases in payload can be obtained even with very small improvements in inlet efficiency at the low speed end.

Special design problems were encountered with the General Electric T-64 engine installation, because of the remote propeller gear box driven by a power shaft protruding forward along the axis of the compressor. This required an "S"-shaped duct which passes around the power shaft, and the intersection of the duct and power shaft gave some concern.

Electrolytic analogy studies of the flow were made using a three-dimensional half model of the duct moulded from fibreglass and filled with tap water. The electric potential was applied through copper plates at each end of the duct and the potential distribution measured with a probe and voltmeter. The results were then applied to the design of the actual duct, which when tested on the engine showed extremely high efficiency. The electrolytic tank method, even though it does not indicate viscous flow effects, was thus shown to be a very useful tool in the design of flow systems of this type.

An interesting discussion period followed the paper. The merits of the offset type of inlet for propeller turbine engines versus the annular type, and the advantages and drawbacks of the electrolytic method were discussed.

The title of the second paper, by Mr. F. N. Dickerman, Assistant Chief Engineer, and Mr. C. F. Branson, Aircraft Division Engineering Specialist, Georgia Division of Lockheed, was "The BLC Hercules – A Practical STOL Transport".

Mr. Dickerman, who read the paper, described the development of the C-130 Hercules airplane incorporating blowing boundary layer control applied to the wing flaps and all control surfaces. This airplane was designed to meet a US Air Force requirement which specifies the ability to carry 20,000 lb of cargo on a radius of 1,000 nautical miles to a midpoint unprepared field with only 500 ft available for ground roll.

On the basis of initial studies on various BLC systems, the blowing system was shown to be superior and was adopted. An extensive wind tunnel test program on a 1/10th scale model was carried out, and a simple flight simulator was built as part of the development programme. The data show that approximately 20% of the total lift during takeoff and landing is produced by the BLC system, and about 50% of the total lift is due to the deflection of the propeller slipstream. BLC was applied to all the control surfaces as well as to the flaps, in order to provide satisfactory flying qualities at the low speeds and low stability levels existing during takeoff and landing.

A description of the hardware was given in the paper, and flight test data were presented which confirmed the performance estimates. A film demonstrating the impressive takeoff and landing performance of the BLC Hercules was shown, and many interesting questions were asked during the discussion period.

The final paper in this session dealt with "Aerodynamics of Blasts" and was presented by Dr. I. I. Glass, Professor of Aeronautical Engineering, UTIA.

Dr. Glass' paper reviewed theoretical and experimental investigations at the Institute of Aerophysics on the blast phenomena associated with spherical and cylindrical explosions. Schlieren and shadowgraph photographs of the shock wave patterns from the explosion of glass spheres and cylinders, pressurized by means of air and combustible mixtures, were shown, and demonstrated good agreement with theoretical predictions. Experiments were also conducted on implosions, underwater explosions and wave interactions. The application of these methods to hypersonic aerodynamic testing, and the dynamic testing of structural components were briefly discussed, and aroused considerable interest during the discussion period that followed the presentation of the paper.

Afternoon Session, October 18th

POWERPLANTS AND PROPULSION

Reported by J. B. Ogle

This session, in which three papers were presented, was presided over by Dean D. L. Mordell of McGill University.

The introduction of the first paper "An Air Breathing Satellite Booster" by Mr. S. Molder and Prof. J. H. T. Wu, who are also at McGill University, gave Dean Mordell an opportunity to stress the importance that is currently attached to this particular topic. As evidence of this fact he informed the meeting that a paper having a similar theme, that was to have been presented, had been cancelled because of security restrictions.

The first paper gave an account of a particular three-stage satellite launching system, the second stage of which was taken to be a recoverable, ram-jet powered, lifting vehicle. This second stage is used to increase the velocity from 1000 ft/sec up to over 12000 ft/sec during a constant climb at an angle of 40°. By making suitable assumptions with respect to the ramjet data, the lift/drag ratio, and the more conventional first and third stage performance characteristics, Mr. Molder was able to show that

Powerplants and Propulsion Session: (l to r) Mr. S. Molder, Prof. J. H. T. Wu, Dean D. L. Mordell (Chairman), Mr. J. C. Vrana and Mr. B. Lubarsky

a payload which is 3.25% of the initial all-up weight can be put into a low orbit. Mr. Molder also estimated that if the staging of the system was optimized the payload fraction could be increased to as much as 8%. This figure represents an order of magnitude improvement on what can be achieved by all-rocket booster systems, and it seems that the ramjet engine may well provide a breakthrough in space booster technology.

The second paper on the "Aerodynamics of the PT6 Gas Path" was given by Mr. J. C. Vrana of Canadian Pratt and Whitney Aircraft Co. Ltd. Mr. Vrana briefly explained the philosophy behind the novel configuration which was adopted for this small turboshaft engine, and then proceeded to discuss in more detail the design and performance, and the air intake and turbine exhaust systems. The speaker also gave an interesting account of the flow paths in the combustion chamber and, in support of this section of his paper, showed a movie of some flow visualization experiments which he had carried out. In winding up, Mr. Vrana indicated that despite the adoption of a complicated gas path, which is imposed mainly by the particular mechanical design, the pressure losses can be kept down to the normal levels associated with gas turbine engines.

The final paper on "Non-Propulsive Power Systems for Long Time Space Application" by Mr. B. Lubarsky and Mr. R. E. English of the Lewis Research Center, NASA, provided the meeting with an account of the basic ideas which have led to the present methods of non-propulsive power generation in earth satellites. Mr. Lubarsky explained the relative merits of several different power sources, including chemical, solar, radio-isotopic and reactor energy, and described in some detail the solar photocell which is particularly suitable for the low level power requirements of present space projects. Turbogenerators are at the moment being developed for higher powered systems of several kilowatts. The speaker also described the thermionic emitter, which appears to be promising but still presents a number of practical difficulties due to the high working temperature necessary for efficient operation.

The meeting was closed with some words of appreciation by the President of the CAI, Mr. David Boyd, who thanked the rather disappointing number of delegates who had stayed until the end.

MID-SEASON MEETING

WINNIPEG

27th and 28th February, 1961

CANADIAN HIGH ALTITUDE RESEARCH SYMPOSIUM

THE Astronautics Section of the Institute held a Symposium in the Chateau Laurier, Ottawa, on the 20th and 21st October. The subject under discussion was the Canadian High Altitude Research Programme, and ten papers were presented covering various aspects of this work. The afternoon of the second day was devoted to an open discussion, led by a panel representative of the organizations most directly concerned. The total registration was 81, of which 33 were non-members of the Institute; in the circumstances this was a satisfactory attendance and the audience played a keen and active part in the proceedings.

Morning Session, 20th October

Dr. P. M. Millman, Head, Upper Atmosphere Research, National Research Council, and Chairman of the Astronautics Section, CAI, was in the chair. In his opening remarks he explained the purpose of the symposium as offering an opportunity for those in Canada interested in the upper atmosphere and space research to review informally the present state of the art and Canadian participation in it, and to consider what further contribution could be made by this country, which was so uniquely situated in relation to the Van Allen belts. He outlined the manner in which the meeting would be conducted, the discussion recorded and so forth, and then called on the first speaker, Dr. D. C. Rose, Chairman of the Associate Committee on Space Research, NRC.

Some Canadian Space Science Objectives

Dr. Rose excused the title of his talk relative to the title of the Symposium by pointing out that the earth's atmosphere merged into the sun's and that, if any dividing line existed, it was almost indefinable. He then referred to the expensive and scientifically valuable competition between the USA and USSR in the penetration of outer space and contended that Canada could make its most effective contribution by confining its research to near space, because of its geographical advantages which the Chairman had mentioned. He outlined some of the fields concerned, astronomy, upper atmosphere physics — in which some surprising discoveries had already been made — ionosphere, aurora studies, geomagnetism and meteorology. Many of these were fields in which Canada had had extensive past experience and background, which could be usefully exploited by the new means now becoming available. He concluded by showing some slides of some of the experiments that had been done.

Dr. P. M. Millman welcoming members to the first session

The discussion of this paper covered such topics as Canada's international contacts and COSPAR, the international Committee on Space Research; the cost of experiments; co-operation with the USA in the launching of Canadian satellites by American rockets; the significance of polar magnetic fields to Canadian research, particularly on cosmic rays; and the British suggestion of a Commonwealth space research programme.

The CARDE Upper Atmosphere Research Programme

The second speaker was Mr. R. F. Chinnick, Superintendent, Electronic Wing, Canadian Armament Research and Development Establishment. Mr. Chinnick explained the interest in the 10 km to 150 km region from the standpoint of defence, the studies conducted by the use of aircraft, balloons and rockets and the instrumentation techniques employed in the measurement, transmission and recording of data.

Morning Session: (l to r) Mr. F. Jackson, Mr. R. F. Chinnik, Dr. P. M. Millman (Chairman), Dr. D. C. Rose and Mr. L. A. Dickinson

The effect of overload on dispersion on landing; the relative costs of the use of balloons and rockets; the overlap and cross-check of data obtained by the use of aircraft, balloons and rockets; the difficulty of obtaining extended observations between the balloon limit (30 miles) and the satellite limit (180 miles); the stabilization of balloon gondolas; and the relative problems of designing instrument packages for use in aircraft, balloons and rockets — all these topics were covered in the discussion following this paper.

Design and Selection of Solid Propellant Rockets for Aerospace Research

This paper was delivered jointly by Mr. F. Jackson of the Ballistics Group and Mr. L. A. Dickinson, Head, Rocket Engine Development Section, CARDE, Mr. Jackson being the first to speak. The iterative process in the step-by-step design of a rocket engine was described. For a given payload and trajectory, the choice of engine dimensions was governed by such factors as staging requirements, external aerodynamics and engine design. Propellants were considered, and the weighing of the merits of high performance propellants, with high flame temperatures, against the associated increase in weight of casing and nozzle. Mr. Jackson dealt primarily with the design requirements, whereas Mr. Dickinson discussed the engineering problems involved. The paper was illustrated by slides.

The discussion covered the use of plug nozzles in solid propellant rockets, thrust losses and the thermodynamics of multiphase working fluids, vector control and asymmetry of thrust, and thrust measurement.

This concluded the session.

Afternoon Session, 20th October

Mr. D. Bogdanoff, Chief Technical Engineer, Missiles and Systems Division, Canadair Limited, and Past Chairman of the Astronautics Section, CAI, took the Chair at the second session, which, as he pointed out, was devoted in the main to the physics of the upper atmosphere.

Experiments in Chemically Seeding the Upper Atmosphere by Rockets

Mr. F. R. Park, Senior Research Officer, Upper Atmosphere Research Section, NRC, described the introduction of suitable chemicals into the upper atmosphere by vertical sounding rockets, as a means of obtaining data on several phenomena. By optical and ground radar observations of the artificial clouds so created information could be obtained on wind, ionization and diffusion, thermo-chemical reactions and electromagnetic propagation. The speaker outlined the experiments and instrumentation required and reviewed some of the work carried out by the USAF Cambridge Research group.

Afternoon Session: (l to r) Mr. F. R. Park, Mr. D. Bogdanoff (Chairman), Mr. G. B. Spindler and Dr. J. H. de Leeuw

Mr. Park's paper evoked only two comments. The first concerning the pollution of the upper atmosphere by such experiments and the second on the production of luminosity by shock fronts.

The Measurement of Major Atmospheric Constituent Concentrations in the 100 km region by a Chemical Seeding Technique

Mr. G. B. Spindler, Project Co-ordinator of the Upper Atmospheric Composition Studies Programme, CARDE, described the method of determining the atomic concentrations of oxygen and nitrogen by releasing nitric oxide into the atmosphere. The reaction of atomic oxygen and atomic nitrogen with nitric oxide is accompanied by the emission of light, the intensity of which is dependent on the reactant concentrations. The speaker described the ground and rocket-borne instrumentation required for the experiment and the measurement of spectral content of this chemiluminesence. He also mentioned two recent experiments carried out at Fort Churchill, the results of which had not yet been fully analyzed; the success of the attempts seemed however to be in some doubt.

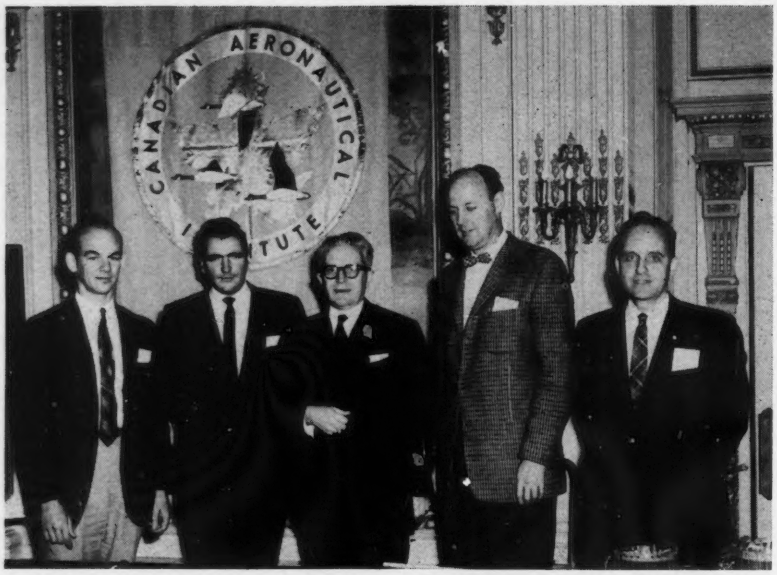
The discussion of this paper included an interesting contribution by Dr. Glass who commented on the use of steel spheres and its effect on the shape of the blast front; he described the work done by the UTIA using glass spheres and cylinders in the study of explosions. The use of laboratory simulators, so far as possible, to avoid misleading conclusions from actual tests was recommended by Dr. Elias of the NAE who cited an interesting example from his experience.

Techniques for the Measurement of the Thermodynamic Properties of the Upper Atmosphere

Dr. J. H. de Leeuw of the Institute of Aerophysics, University of Toronto, presented the final paper, of which he and Dr. G. N. Patterson, Director, UTIA were joint authors. The paper described the development of method for the measurement, at high speed, of such properties as pressure, density and temperature. Instruments for low pressure measurement at speeds encountered in rocket flight were being prepared and the electron gun was being studied for possible application to the measurement of both density and temperature.

The paper was presented in two parts, with a brief discussion after the first; the second part essentially referred to the application of the techniques to rocket experiments. There was no discussion at the end of the paper.

The discussion after the first part, arising from a question by Mr. Chinnick, concerned the method used to obtain rotational spectra of the nitrogen ion and the elimination of self-emission from the nitrogen stream.



Morning Session: (l to r) Dr. W. J. Heikkila, Dr. J. B. McDiarmid, Prof. G. S. Glinski (Chairman), Prof. P. A. Forsyth and Dr. P. M. Millman.

Morning Session, 21st October

The Chairman of the third session of the Symposium was Professor G. S. Glinski of the University of Ottawa, Vice-Chairman of the Astronautics Section. After pointing out that the session must run to a rigid timetable since four papers were to be presented, the Chairman introduced Dr. W. J. Heikkila, Head of the Rocket Section, DRTE, who was to deliver the first paper. Dr. Heikkila's co-authors were Dr. A. W. Adey, Mr. S. R. Penstone and Mr. W. K. Lacey, all Research Scientists in his Section.

Rocket Studies of Ionosphere Absorption

Dr. Heikkila's paper described the purpose and conduct of the high latitude radio-absorption experiments carried out at Fort Churchill during 1960. The study of events occurring after major solar flares, known as Polar Cap Absorption Events, was disappointing because no suitable events occurred since July and therefore attention was directed to auroral absorption. In addition to absorption, experiments were devised to measure electron density and Dr. Heikkila described the instrumentation which was admittedly still in an experimental stage itself. The paper concluded with an account of two recent firings, one into auroral absorption and the other into a weak Polar Cap Event. Both were only partially successful and it was too early to report results. It was hoped that a third firing could be made before winter set in. Dr. Heikkila then showed some slides of the nose cone and various activities at the range.

The discussion of this paper was fairly short, dealing with the time sequence of firings in these relatively short auroral events – for which purpose Dr. Heikkila expressed his appreciation of the use of solid-propellant rockets – the sources of the equipment, whether government laboratory or industry, and the altitude which rockets should be capable of attaining in this work.

Measurements of Charged Particles above the Atmosphere

The second paper was presented by Dr. I. B. McDiarmid of the NRC. He described the experiments being carried out by the Cosmic Ray Section to study various types of charged particles at high altitudes. Measurements of total primary cosmic ray intensity near a solar maximum in September 1959 were compared with values obtained by Van Allen's group near a solar minimum in 1952. Dr. McDiarmid also referred to the experiments carried out this summer, which had been mentioned by Dr. Heikkila. He concluded with an outline of plans for a future experiment with the DRTE Topside sounder satellite.

The discussion of this paper centred around the accuracy with which the height could be correlated with the absorption measurements, and conversely the possibility of using the absorption as a measure of altitude.

A Falling Sphere Electron Density Experiment

Professor P. A. Forsyth of the Institute of Upper Atmospheric Physics, University of Saskatchewan, presented the third paper. Mr. A. Kavadas, co-author of the paper, was not present.

Professor Forsyth started by pointing out that the title of the paper should be changed to "A Falling Package", since so many things had been hung on the outside that it was no longer a sphere. He then explained the difficulty of obtaining reliable electron density measurements in the ionosphere during an auroral display by normal propagation methods because of the inhomogeneous auroral atmosphere, and described the studies made by the NASA team at Fort Churchill in September 1959 in an attempt to evolve a more effective method for electron density measurements. With this background, he outlined plans for an experiment, to be carried out next year, using three instrumented packages, discharged laterally from a rocket nose cone at 120° spacing in azimuth; each would transmit continuously along its particular trajectory so that three sets of measurements, from three positions, could be monitored simultaneously from the ground. In this way the electron density profiles for three separate paths through the ionosphere can be measured.

Following the paper the discussion covered such matters as the relative importance of knowing the trajectories of the packages, the desirability of using the nose-cone itself as a probe and possible effects of the rocket on the electron density in its immediate environment, and the effect of the capacity of the package and the magnetic field. The relationship of the wavelength to the ion sheath formed around the antenna was considered at some length.

The Use of Artificial Satellites and Rockets in the Study of Meteoritic Bodies

Appropriately, as Professor Glinski pointed out, the last paper was presented by Dr. Millman, Chairman of the Astronautics Section.

Dr. Millman described the techniques employed in recording and measuring the effects of high velocity impacts of meteoritic particles on rockets and artificial satellites. These effects include the cratering, ablation or breaking of the units on exposed surfaces, and the propagation of shock vibrations and luminosity. Limiting masses detectable vary from 10^{-8} to 10^{-14} grams, and impact rates in the range 0.01 to 100 m^{-2} sec^{-1} have been observed. The speaker pointed out however that comparison of various sets of results showed wide discrepancies, not yet fully explained.

There was a good deal of discussion of this paper including an observation by Dr. Halliday of the Dominion Observatory that the more recent experiments seemed to show poorer sensitivities than earlier ones, a point which Dr. Millman could attribute only to increasing ruggedness of equipment. Dr. Bull

Dr. J. J. Green addressing the audience at the opening of the Panel Discussion

also referred to the progress being made in the simulation of high energy impacts in the CARDE range and Professor Forsyth raised an interesting point about the effect of the relative directions of travel of the particles and the satellite on the numbers of impacts recorded. The discussion also covered the general study of meteoric density measured by various terrestrial and airborne methods and the problems of terrestrial contamination which made such studies difficult and unreliable.

The session was then adjourned.

Afternoon Session, 21st October

The closing session of the meeting took the form of a general discussion, led by a panel under the Chairmanship of Dr. J. J. Green, Chief Superintendent of CARDE. Members of the panel were Mr. D. Bogdanoff of Canadair, Dr. G. V. Bull of CARDE, Dr. J. H. Chapman of DRTE and Professor P. A. Forsyth of the University of Saskatchewan.

After introducing the members of the panel, Dr. Green explained that each would say a few words about his particular field of endeavour and that then the discussion would be thrown open to the floor and he urged everyone present to take an active part. He first called upon Mr. Bogdanoff.

Mr. Bogdanoff spoke cf the position of industry in Canadian high altitude research and pointed out that no paper in the programme had been presented by an industry representative; industry, he felt, was being left out. He referred to the limited part played by his own company, Bristol and De Havilland, and pointed out that orders were generally small and let out piecemeal on competitive tender, which made it very difficult for industry to handle them; it often cost more to prepare the bids than to do the job. He suggested two solutions, firstly that small orders should be combined to make bigger ones and secondly that, if the combining of orders was impossible for budgetary reasons, small orders should be negotiated directly with the selected company and not put out to tender. He thought that, by one or other of these means, industry would be able to play a more significant part and, in so doing, would keep its technical teams together. Thus the talent now available in industry could be developed to the ultimate benefit of the programme as a whole.

Dr. Bull started by expressing the opinion that the interpretation of data was a major weakness in the present programme. He went on to describe in some detail the free flight firing range work being carried on at CARDE and suggested that there should be clcser co-operation between the various groups concerned with any programme to eliminate duplication, promote simulation experiments and generally to reduce cost; he cited Topside as an admi able example of such co-operation between Canadian and American interests.

Dr. Chapman pointed out that DRTE had been working on the electrified portions of the atmosphere for a long time, because of the importance of the ionosphere to communications and ultimately to defence. All that has changed recently has been the emergence of new techniques, including the use of rockets carrying instruments. He mentioned the Topside sounder as another step forward in this process of ionosphere research. For the future Dr. Chapman saw little material change in the DRTE programme. Finally he raised the question of the size of the space research programme appropriate and desirable for Canada; these programmes were expensive and other fields of scientific research had parallel claims. He suggested that this important question should be carefully considered and discussed from the point of view of economics.

Professor Forsyth discussed the role of the universities in space research. He pointed out that, though university research teams and facilities were small, they could contribute usefully to some of the many facets of the subject and possessed the unique quality of having available a wider diversity of talent than could be found in any government

Panel Discussion: (l to r) Prof. P. A. Forsyth, Dr. J. H. Chapman, Dr. J. J. Green (Chairman), Dr. G. V. Bull and Mr. D. Bogdanoff

laboratory or in industry. He also emphasized the all-important role of the universities in training people; he was sure that the Canadian research programme would grow to substantial proportion in the next ten years and pointed out that the people who would be responsible for this work must be trained by the universities now. Moreover with the expanding capabilities of the rocket as a research tool ground-based laboratory work would have to expand proportionally, to back up the rocket and satellite experiments. Commenting on Dr. Chapman's question about the size of the Canadian programme, Professor Forsyth said that there was no choice; in view of Canada's unique background and unique location, the Canadian programme must keep pace with the work that other countries are doing.

After each member of the panel had spoken, the Chairman neatly summarized his remarks and now he threw the discussion open to general discussion.

Based on the opening remarks by the panel the discussion flowed to and fro for nearly two hours. It ranged over considerations of specific unsolved problems; the relative costs of Canadian and American work and means for publicizing and arousing interest in Canadian upper atmosphere research with a view to attracting the allotment of more money to it; the scope of the Canadian programme and the establishment of objectives compatible with the country's resources and rate of growth; and an argument about industry's participation, the important contributions that industry could make if it were given a bigger share of the work, and the relative responsibilities of industry and government establishments for research and development – here the lines were fairly clearly drawn between the representatives of industry and the government scientists. No very firm conclusions were reached but it was a useful airing of views. It was generally agreed that the programme, as a programme, was fairly satisfactory – though the industry seemed unconvinced that the work was being distributed as wisely as it might be, and some of those present favoured a clearer and more specific definition of objectives.

At the close of the discussion the Chairman handed the meeting over to Dr. Millman, who, as Chairman of the Astronautics Section, made the closing remarks. He announced that he had had a message from the President, Mr. David Boyd, expressing his regrets at being prevented from attending, and sending his greetings. He than thanked all those who had participated and declared the meeting adjourned.

COMING EVENTS

SAE

9th-13th January, 1961 — *International Congress and Exposition of Automotive Engineering,* DETROIT, MICHIGAN.

IAS

29th-31st January, 1961 — *30th Annual Meeting,* HOTEL ASTOR, NEW YORK.

CAI

27th-28th February, 1961 — *Mid-season Meeting,* WINNIPEG, MAN.

Toronto

5th January – UTIA, *The Jet Flaps,* DR. D. A. SPENCE, ROYAL AIRCRAFT ESTABLISHMENT.

Ottawa

11th January – *Crash Position Indicator,* MR. H. T. STEVINSON.

15th February – *Navigation System for a Mach 2 Transport,* W/C K. R. GREENAWAY.

Edmonton

14th February – *Development of the Douglas DC-8,* G. L. FARQUHAR, ASST. CHIEF PROJECT ENGINEER–DC-8, DOUGLAS AIRCRAFT.

Vancouver

18th January – RCAF OFFICERS' MESS, SEA ISLAND, *Panel Discussion on Constant Frequency versus Frequency Wild Generating Systems for Aircraft.*

February – *Joint CAI/SAE Meeting.*

BRANCHES

Montreal

Reported by J. R. Chadborn

Seventh Annual Golf Tournament

The Seventh Annual Golf Tournament of the Montreal Branch took place at St. Andrews Country Club on Friday the 26th August, 1960.

In spite of the Montreal-Toronto football game, 108 members and guests turned out to play golf in almost perfect golfing weather. In the evening, 94 enjoyed the excellent buffet supper.

The Branch Chairman, Mr. D. R. Taylor, welcomed the assembly, and the presentation of prizes was carried out by the writer with the able assistance of Mr. D. Stevens. The E. B. Schaefer Memorial Trophy was won by Mr. A. Nicholls, with a low gross of 83. (W/C M. T. "Max" Friedl, who has won this Trophy in the last two Tournaments, was unable to be present due to RCAF duties in Europe.)

The Bob Wright Memorial Trophy was won by G/C E. P. Bridgland, also with low gross 83. (The allotment of these Trophies was decided by the toss of a coin.)

Hitherto it has been our policy to leave the competition for the E. B. Schaefer Trophy open to all members of the CAI and the Bob Wright Trophy open to members of the Montreal Branch only. However, due to various complications arising out of this arrangement, it has been decided to leave the competition for both Trophies open to all members of the CAI.

The Ross Trophy, open to non-member guests, was won by F/Sgt W. J. Bavin, with a low gross 89.

There was a splendid array of prizes, both donated and purchased, and I wish to extend our thanks, at this time, to the friends who kindly volunteered to augment our supply of prizes.

In closing I wish to thank the Ticket Committee, namely, Mr. R. J. Conrath, Mr. W. R. Cuff, Mr. C. G. MacLeod, Mr. A. Lavendel, Mr. B. K. Ryan, Mr. E. McCallum, Mr. T. A. Harvie, and Mr. J. R. Holding for their splendid support.

Halifax-Dartmouth Branch Executive Committee
Standing: (l to r) V. W. Bowers, CPO A. C. Green, Lieut. J. A. Turner and CDR E. B. Morris. Sitting: (l to r) R. Wallworth, LCDR G. M. Cummings and Prof. O. Cochkanoff

Halifax-Dartmouth

Reported by F. T. Dryden

October Meeting

The regular meeting was held in the cinema of the Chief Petty Officers' Mess, HMCS Shearwater, on Wednesday the 19th October, 1960. A total of 57 members and guests were present. The Branch Chairman, LCDR G. M. Cummings, presided over the meeting.

This meeting was held in two parts, the first part being held in "Z" Hangar of the School of Naval Air Maintenance, where instructors from the school explained and operated the various training aids, including the working panels of the actual mechanical, hydraulic and electrical systems of the Tracker and Banshee aircraft along with a full-size working model of the HO4S Helicopter. Static displays included sectioned models of the Westinghouse J34WE34 engine, Wright Cyclone 983C9HE1 and the Hamilton Hydromatic fully feathering propeller.

Members and guests then assembled in the cinema of the CPO's Mess for the second or business part of the meeting.

The Chairman formally opened the meeting at 9.30 pm by welcoming the large number of guests present. Presentation of certificates of membership was then made to Mr. F. R. Brown and LCDR S. Grossmith, by the Chairman.

The Chairman then stated that a brief had been submitted by Mr. F. T. Dryden with reference to an attempt to break the world air speed record for a single engine, piston driven aircraft; the present record being set in 1939 by Captain Fritz Wendel in a ME 109R, attaining a speed of 469.22 mph. As the Branch Executive had already discussed this brief at length in committee, and as time was running short, it was decided that no discussion would be held at this meeting, but that Mr. Dryden would be asked to carry out further research into the project and report back to the executive.

Professors Cochkanoff and Vail of the Nova Scotia Technical College discussed, with interested members, courses in Aerodynamics and Electronics being given in the extension department of the college.

After a brief intermission a film on High Speed Flight was shown.

At the end of the meeting, Mr. E. C. Garrard said a few words of appreciation to LCDR Brown, Officer in Charge, Naval Air Maintenance School, for such an impressive and enlightening tour of the school's facilities. Appreciation was also shown the instructors – Petty Officers Sorrel, Hodgson, Lee and Grant – for the superb manner in which they delivered the lectures, on the various items of equipment, and the expert fashion in which they answered the many questions they were given to deal with.

Toronto

Reported by K. A. Kinsman

October Meeting

The October meeting was held at the Institute of Aerophysics (UTIA) on Thursday, 13th October, 1960, at 8.00 pm. Mr. W. T. Heaslip, the Branch's Vice-Chairman, chaired this meeting and welcomed 72 members and 23 guests to hear Mr. W. Z. Stepniewski of Vertol. Mr. Heaslip explained that this was a joint meeting with the UTIA and he expressed the Branch's thanks for making the speaker's visit to Toronto possible.

Prof. B. Etkin of UTIA introduced Mr. W. Z. Stepniewski, who is presently the Assistant Director in charge of Research at the Vertol Division of the Boeing Airplane Company. Mr. Stepniewski left The De Havilland Aircraft of Canada in 1946, where he was the Head of Aerodynamics and Stress, to go to Piasecki and then to Vertol.

Mr. Stepniewski presented a paper titled "VTOL in Perspective", which, as he explained, was a review of VTOL vehicles to date. His paper was illustrated with many slides and several short films.

VTOL vehicles are needed to go from A to B as quickly as possible with minimum delays at the end points. The only operational VTOL vehicle is the helicopter which is limited to below 200 mph. The tilt wing, tilt ducts and tilt rotor types are limited to below 500 mph while the jet support VTOL has unlimited capabilities. GETOL (ground effect takeoff and landing) vehicles are still very experimental. Mr. Stepniewski discussed safety during hovering with respect to engine failure and its effect on height and speed. Several slides were shown giving a time history of an engine failure and its effect on height and speed. Several slides were shown giving a time history of an engine failure during hovering of a twin engine, twin rotor helicopter, and illustrating how stored rotor energy can be used to soften the landing by application of collective pitch. A short film was shown illustrating this technique.

Mr. Stepniewski followed with an outline of the tilt wing and GETOL vehicles. He described in detail the problems associated with their three flight phases (hovering, transition and cruise flight). The greatest problem with the tilt wing is keeping the wing unstalled during its rotational stage.

After a short film was shown on a GETOL vehicle, the meeting was adjourned for a quick coffee break. A film on the tilt wing and a very lively discussion period followed. Mr. W. T. Heaslip called a halt to the discussion at 10.45 pm, since Mr. Stepniewski had been talking for approximately 2½ hours.

Mr. R. D. Hiscocks, Assistant Chief Engineer of De Havilland, thanked Mr. W. Z. Stepniewski for his most interesting and at times quite humourous talk.

Mr. Heaslip adjourned the meeting after announcing details of the next meeting which will be held on the 23rd November, 1960, at the De Havilland cafeteria, where Mr. Lombard of Rolls-Royce will talk on aircraft turbine engine development.

Calgary

Reported by F/O L. A. Flaherty

October Meeting

The second general meeting of the Calgary Branch was held in the Al San Club, Calgary, at 8.00 pm on the 19th October. This was a Dinner Meeting followed by a talk by a guest speaker.

In addition to the speaker, there were a number of guests attending; Mr. C. Farrell, Assistant Manager of Canadian Pacific Air Lines (Repairs), Limited; Mr. L. Cook, Assistant Plant Superintendent of CPA(R)L; Mr. B. Mossman, Foreman of the Motor Transport Section of CPA(R)L; Mr. Tubby Jarrett from Home Oil, and Dr. R. H. Chant from Yorkton, Saskatchewan.

There were 19 members in attendance, 5 guests and 12 student members.

Following the dinner and a short business meeting, the Chairman, Mr. G. H. Fenby, called on the Chairman of the Programme Committee, Mr. J. M. Robertson, to introduce the guest speaker. Mr. Robertson introduced Mr. L. W. Olson, Assistant Manager of Service Engineering for United Air Lines, San Francisco, California, and gave a brief résumé of his activities. Mr. Olson then gave his talk on the DC-8, with emphasis on the troubles they had already experienced, and the methods and solutions arrived at to correct these troubles. He supported his talk with slides illustrating curves, jet-ways for loading and unloading, and baggage handling. He drew comparisons between the JT-3, JT-4 and JT-1 engines and outlined some of their good points. He explained the problem they were having with the seals in the main landing gear struts which tend to distort, and the solution they were working on to correct it. He pointed out his feelings that new or existing design should be searched very closely to ensure that they cannot be simplified, since we seem to be reaching the maximum in automation and even protective devices can get you into trouble.

It is interesting to note that the JT-3 engine is going 1200 hours to overhaul and the JT-4 1000 hours. The DC-8 airframe goes 2500 hours before overhaul and UAL have perfected their maintenance to the point where they can complete this overhaul in a period of five days. Maintenance checks are carried out every 200 hours and the aircraft returned to service within 24 hours. In their San Francisco shops, UAL can change a JT-3 or JT-4 engine in 4 to 6 hours. Elsewhere it takes considerably longer.

Pre-flight inspections are carried out at approximately 22 hours flight time, and never more than 30 hours.

At the conclusion of his speech, Mr. Olson thanked the CAI for the opportunity to speak, and answered questions directed by the members. At the conclusion of the question period, Mr. W. Robertson thanked Mr. Olson for his very interesting talk, and expressed the wish that he might, at a later date, have occasion to come back and visit the Calgary Branch.

Edmonton

Reported by H. Robertson

October Meeting

The October meeting of the Edmonton Branch was held at 700 Wing RCAF Association on the 18th October. 25 members and 4 guests attended.

The Branch Chairman, Mr. R. W. Van Horne, chaired the meeting, and, after a brief business period, invited Mr. A. J. Quick to introduce the speaker of the evening, Mr. I. S. Macaskill of the Department of Transport.

Mr. Macaskill spoke on the subject of the new Edmonton International Airport, and gave a very interesting talk on the reasons leading up to the necessity of such a project being undertaken by the DOT.

In the choice of land, which would make possible the use of existing navigational aids, several sites were considered in the vicinity of Edmonton. The final choice was made to buy a large tract of land in the Leduc district, about 16 miles south of Edmonton. Since construction has started, the runways are long enough to handle all types of aircraft, and enough land has been acquired to make large extensions if and when required. It is believed that when completed it will rank the most modern and best equipped airport in the Dominion.

After a short discussion period, the speaker was thanked on behalf of those present by Mr. C. C. Young.

Vancouver

Reported by M. G. Brechin

October Meeting

The October meeting of the Vancouver Branch was held on October 18th, 1960, at the Delmar Supper Club, and was attended by 51 members and 13 guests.

After a very enjoyable dinner, the Chairman, Mr. F. L. Hartley, called the meeting to order and welcomed the members and guests.

Mr. R. J. McWilliams, Past Chairman, introduced the speaker, Mr. L. W. Olson, Assistant Manager of Service Engineering for United Air Lines. Mr. Olson presented a very interesting and informative talk entitled "A Report on Operations and Maintenance Performance of the DC-8 Airplane". Mr. Olson, educated at the University of Wisconsin and the Milwaukee School of Engineering, is well qualified to speak on the subjects, having come up through the ranks of UAL after starting his career as a mechanic in 1939. In 1945 he was transferred to Operations Engineering and assigned various engineering projects on the DC-4 and DC-6 airplanes. In 1948 he came to his present position where he is, along with other duties, the Chairman of the DC-8 Development and Turbine Technical Board.

The report dealt mainly with the mechanical problems encountered and the "fixes" performed on the UAL fleet of 30 DC-8 aircraft, since their inauguration into service on June 14th, 1959.

It was evident that mechanical troubles which keep a five million dollar airplane on the ground must be given priority attention in "identification of trouble by accurate diagnosis, repair and engineering follow-up with modification, to successfully maintain high utilization on time performance", with an airplane that can gross $50,000 a day.

A case in point was a problem with flush toilets, which was not to be overlooked; "A five million dollar airplane with a "john" that doesn't work gets high level attention."

It is obvious that thorough training of personnel working on expensive jet equipment is essential. In many instances much more trouble than the original problem was presented due to "finger" trouble and inaccurate diagnosis of mechanical irregularities. This is compounded by the ever increasing "Buck Rogerish" type circuits and systems, sometimes triple protection for one type of failure, in jet equipment. The back room design boys should be persuaded to take a new look at simplicity, as future supersonic designs do not have to be as complicated or sophisticated as the present jet aircraft. Engine failures are comparatively rare compared with piston equipment. UAL enjoyed a phenomenal engine operation of 66,000 hours before they experienced an engine failure — a failure being defined as a malfunction of the basic engine necessitating replacement.

Availability of spares which has long plagued the air transport industry is a real problem with the DC-8. For example an engine can be changed at a line station in approximately 6 to 8 hours providing the spare engine has not been "robbed" for spares, which, if the case, can extend the time required to over 20 hours. The manufacturers and suppliers of spare parts for costly jet equipment are possibly aware of this serious problem of spare parts supply, but must accept a much greater obligation and responsibility to provide parts to meet the operators demands than they have shown in the past for piston type aircraft.

After a short question period, the speaker was thanked by Mr. P. Muncaster of TCA, who stated he hoped to see the DC-8 become as reliable and attached as the DC-3. It appeared that UAL were well on their way to achieve the hope.

Winnipeg

Reported by C. P. Gulland

October Meeting

The second dinner meeting of the current season was held on October 25th at the Winnipeg Flying Club. Approximately 40 members and guests attended.

The Chairman, W/C C. J Evans, called the meeting to order on completion of the dinner. A short business session was followed by the introduction of two new members.

Mr. E. W. Baker introduced the speaker of the evening, Mr. J. M. MacTavish, General Manager of the Fort Garry Tire and Auto Supply in Winnipeg.

Mr. MacTavish entitled his paper "Safety Requirements of the Modern Jet Aircraft Tire". After his opening remarks he had a film shown which covered the manufacture of an automobile tire. From this base, the speaker went on to compare a specific jet aircraft tire with a specific automobile tire, both of which had similar outside dimensions. The jet tire carried twelve and one-half times the load, nine times the pressure and operated at more than twice the deflection and speed of the automobile tire. However, it was pointed out that this vast difference was due mainly to the intermittent duty cycle of the aircraft tire. Continuous operation under these conditions would generate a destructive amount of heat.

By means of slides, Mr. MacTavish graphically illustrated the following points:

(1) The reduction in tensile strength of tire compounds with increased temperature.

(2) Reduction in adhesion — tread to body with increase in duty.

(3) Strength loss of nylon with increase in temperature.

(4) Deflection versus inflation for a specific tire and load.

(5) Temperature build up at 40 mph with 32% and 40% deflection.

Along with the explanation of the slides, the speaker described the various types and causes of tire failures. Deterioration due to heat seemed to be the major problem. In the supersonic aircraft presently contemplated, it appears that the wheel nacelle temperatures expected are higher than the curing temperatures of rubber.

An impartial discussion of the merits of nylon, rayon and "Tyrex" cords indicated that each had its place in the tire industry. Nylon cord being used almost exclusively in the present high speed aircraft tires.

Recommendations for improving the performance and safety of jet aircraft tires were given, some of which are as follows: regular inspections, paying particular attention to actually checking the inflation pressure. X-ray inspection to disclose defects within the tire body prior to retreading tires. Designers are encouraged to use tires of adequate size and carrying capacity. Wheel designs of a type to avoid the transfer of heat to the tire, and which will permit the mounting of a tire without damage to the tire or rim.

The question period which followed was quite extensive and finally had to be called to a halt by the Chairman.

Prof. H. J. T. Young thanked the speaker on behalf of the Branch.

Ottawa Student Section, Kingston

At the last meeting of the Student Section at the RMC, Kingston, the following were elected to the Student Executive:

Chairman
F/C G. Paquet

Secretary
F/C T. A. Spruston

MEMBERS

NEWS

C. C. Barker, M.C.A.I., has recently taken a position with The De Havilland Aircraft of Canada Ltd. as a Design Engineer.

D. R. Wright, M.C.A.I., formerly with Canadair has moved to the USA to take up the position of Design Specialist with the Boeing Airplane Co., Renton.

G. P. Berthin, Technical Member, has taken a position as a Project Engineer with Aviation Electric Ltd. in Montreal.

W. J. Mann, Associate, formerly General Manager of Canadian Curtiss-Wright has been elected Vice-President and a Director of the Company.

P. R. Tolley, Consulting Engineer—Resident, General Electric Company, Cincinnati, Ohio: *Orenda Engines Ltd., Box 4015, Terminal A, Toronto, Ont.*

Associate

J. M. Bogie, Executive Vice-President, Laurentian Air Services Ltd., P.O. Box 4070 Station E, Ottawa, Ont.

* * *

ADMISSIONS

At a meeting of the Admissions Committee, held on the 28th September, 1960, the following were admitted to the grades shown.

Associate Fellow

R. F. Chinnick, Superintendent Electronics Wing, Canadian Armament and Research Establishment, Quebec, P.Q.: *1292 Dubnisson St., Sillery, P.Q.*

J. A. Morley, Co-ordinator—Cargo Systems, Canadair Limited, P.O. Box 6087, Montreal, P.Q.

Member

L. R. Camphaug, Maintenance Supervisor, Spartan Air Services Ltd., Ottawa, Ont.: *2503 Clover Ave., Ottawa, Ont.*

F/L R. Dignum, RCAF, Technical List/Telecommunications Branch, Department of National Defence, Ottawa, Ont.: *Royal Military College, Kingston, Ont.*

At a meeting of the Admissions Committee, held on the 26th October, 1960, the following were admitted to the grades shown.

Member

LCDR N. L. Brown, Officer-in-Charge, Naval Aircraft Maintenance School, Shearwater, N.S.

F/L T. E. Ervine, RAF (Retd), Aero Service Dept., Rolls-Royce of Canada Ltd., Box 1400, St. Laurent, Montreal 9, P.Q.

Mr. F. A. H. Harley, Chief Pilot (Helicopter Div.), Spartan Air Services Ltd., 2117 Carling Ave., Ottawa 3, Ont.: *2060 Knightsbridge Road, Ottawa 3, Ont.*

Mr. A. G. K. Mayo, Contracts Manager, Godfrey Engineering Co. Ltd., 480 Metropolitan Blvd., Montreal, P.Q.: *5600 Raymond Ave., Pierrefonds, P.Q.*

Mr. C. F. Tinley, B.C. Vocational School, Burnaby, B.C.: *2555 Walker Ave., South Burnaby, B.C.*

D. V. Bowley (on transfer from Technical Member)

Technical Member

L. Zelen (on transfer from Junior Member)

Student

E. Alzner, McGill University, Montreal, P.Q.: *7690 - 2nd Ave., Montreal 38, P.Q.*

F/C F. A. Archibald, Fort Haldimand, Royal Military College, Kingston, Ont.

A. Bazergui, Ecole Polytechnique, Montreal, P.Q.: *806 Rockland Ave., Outremont, Montreal 8, P.Q.*

F/C A. G. Blaikie, Fort Lasalle, Royal Military College, Kingston, Ont.

M. Castracane, McGill University, Montreal, P.Q.: *2246 Oxford Ave., Montreal 28, P.Q.*

F/C J. E. R. Drouin, Fort Haldimand, Royal Military College, Kingston, Ont.

F/C J. J. P. Filiatrault, Fort Haldimand, Royal Military College, Kingston, Ont.

M. C. Hutchins, McGill University, Montreal, P.Q.: *2227 O'Brien Blvd., Ville St. Laurent, Montreal 9, P.Q.*

V. K. Jyoti, McGill University, Montreal, P.Q.: *3424 Drummond St., Apt. 7, Montreal, P.Q.*

F/C J. P. Langlois, Royal Military College, Kingston, Ont.

O. Levesque, Ecole Polytechnique, Montreal, P.Q.: *2963 Maplewood Ave., Montreal 26, P.Q.*

K. L. R. Mok, McGill University, Montreal, P.Q.: *c/o Engineering Bldg., McGill University, Montreal, P.Q.*

A. C. Niderost, McGill University, Montreal, P.Q.: *51 Dufferin Road, Montreal 29, P.Q.*

F. O. Okulaja, McGill University, Montreal, P.Q.: *3465 Jeanne Mance, Montreal, P.Q.*

F/C O. Y. Poirier, Fort Haldimand, Royal Military College, Kingston, Ont.

F/C G. Paquet, Fort Haldimand, Royal Military College, Kingston, Ont.

APPOINTMENT NOTICES

The facilities of the Journal are offered free of charge to individual members of the Institute seeking new positions and to Sustaining Member companies wishing to give notice of positions vacant. Notices will be published for two consecutive months and will thereafter be discontinued, unless their reinstatement is specifically requested. A Box No., to which enquiries may be addressed (c/o The Secretary), will be assigned to each notice submitted by an individual.

The Institute reserves the right to decline any notice considered unsuitable for this service or temporarily to withhold pulication if circumstances so demand.

Assistant Development Engineer: Bachelor's Degree in Mechancial Engineering or British Higher National Certificate in Mechanical Engineering. Member of a Provincial Association of Professional Engineers or eligible for such membership, with at least three to five years total experience in the following fields: basic design of small mechanisms, design of small hydraulic and pneumatic components, design of small jigs, tools and fixtures as applied to the Plastics industry. Candidates must be competent draftsmen, able to sketch, lay out and work up details. An engineering apprenticeship would be an added advantage. They must also be clearable with the Canadian Department of National Defence, up to Secret level.

The successful applicant will be required to assist the Company's Development Engineer with project studies, to draft reports and to carry out design and experimental work. The Company is presently engaged in the development of a portable plastics injection moulding gun which has wide application in the industrial field.

Salary range: $6,000.00-$7,500.00 per annum according to qualifications and experience.

Applications to be forwarded to: Manager, Industrial Relations, Northwest Industries Limited, P.O. Box 517, Edmonton, Alberta.

SUSTAINING MEMBERS

of the

CANADIAN AERONAUTICAL INSTITUTE

1960-61

AEROQUIP (CANADA) LIMITED

AIRCRAFT INDUSTRIES OF CANADA LIMITED

ALLOY METAL SALES LIMITED

AVIATION ELECTRIC LIMITED

A. V. ROE CANADA LIMITED, AERONAUTICAL GROUP

BRISTOL AERO-INDUSTRIES LIMITED

CANADAIR LIMITED

CANADIAN FLIGHT EQUIPMENT COBOURG LTD.

CANADIAN PACIFIC AIR LINES LIMITED

CANADIAN PRATT & WHITNEY AIRCRAFT COMPANY LIMITED

CANNON ELECTRIC CANADA LIMITED

CARRIERE AND MACFEETERS LIMITED

COLLINS RADIO COMPANY OF CANADA LIMITED

COMPUTING DEVICES OF CANADA LIMITED

DEHAVILLAND AIRCRAFT OF CANADA LIMITED

D. NAPIER & SON (CANADA) LIMITED

DOWTY EQUIPMENT OF CANADA LIMITED

ENAMEL & HEATING PRODUCTS LIMITED

FAIREY AVIATION COMPANY OF CANADA LIMITED

FIELD AVIATION COMPANY LIMITED

GARRETT MANUFACTURING LIMITED

GENERAL CONTROLS CO. (CANADIAN) LIMITED

GODFREY ENGINEERING COMPANY LIMITED

HONEYWELL CONTROLS LIMITED

IMPERIAL OIL LIMITED

IRVIN AIR CHUTE LIMITED

JARRY HYDRAULICS LIMITED

LUCAS-ROTAX LIMITED

MOFFATS LIMITED (AVCO OF CANADA)

NORMALAIR (CANADA) LIMITED

NORTHWEST INDUSTRIES LIMITED

OKANAGAN HELICOPTERS LIMITED

PRENCO PROGRESS & ENGINEERING CORPORATION LIMITED

RAILWAY & POWER ENGINEERING CORPORATION LIMITED

ROLLS-ROYCE OF CANADA LIMITED

ROUSSEAU CONTROLS LIMITED

SHELL OIL COMPANY OF CANADA LIMITED

SIMMONDS AEROACCESSORIES OF CANADA LIMITED

S. SMITH & SONS (CANADA) LIMITED

STANDARD AERO ENGINE LIMITED

TRANS-CANADA AIR LINES

WALTER KIDDE & COMPANY LIMITED

YORK GEARS LIMITED

APPOINTMENT NOTICES

The facilities of the Journal are offered free of charge to individual members of the Institute seeking new positions and to Sustaining Member companies wishing to give notice of positions vacant. Notices will be published for two consecutive months and will thereafter be discontinued, unless their reinstatement is specifically requested. A Box No. to which enquiries may be addressed (c/o The Secretary) will be assigned to each notice submitted by an individual.

The Institute reserves the right to decline any notice considered unsuitable for this service or temporarily to withhold publication if circumstances so demand.

Membership in the C.A.I.

is becoming widely recognized as a significant qualification in Canadian aviation and particularly for those engaged in technical work — research, design, engineering, manufacture, maintenance, operation etc. Annual dues range from $3.00 to $15.00 depending on the member's qualifications and grading.

Information and applications for membership can be obtained from the Secretary of the Institute or from Branch Secretaries as follows:

K. A. Kinsman,
30 Muircrest Drive,
Don Mills, Ont.

W/C H. J. M. Londeau,
Detachment Commander,
1102 TSD, RCAF,
Canadair Ltd., P.O. Box 6087,
Montreal, P.Q.

Lt. J. M. Vivian,
16 Virgil Road,
Bells Corners, Ont.

Mr. M. G. Brechin,
670 Comstock Road,
Richmond, B.C.

Mr. E. W. Baker,
3809 Curthbertson Ave.,
Charleswood, Man.

Mr. H. Robertson,
P.O. Box 121,
Edmonton, Alta.

CPO A. C. Green,
P.O. Box 104,
Shearwater, N.S.

F/O D. N. Bailey,
Officers' Mess, RCAF Station,
Cold Lake, Alta.

F/O L. A. Flaherty,
PMQ 151, RCAF Station,
Lincoln Park, Alta.

Dr. C. I. H. Nicholl,
2527 des Hospitaliers,
Sillery, P.Q.